CRANFIELD UNIVERSITY

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The influence of market structure, collaboration and price competition on supply network disruptions in open and closed markets

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PhD
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ABSTRACT

The relaxation of international boundaries has enabled the globalisation of markets making available an ever increasing number of specialised suppliers and markets. Inevitably this results in supply chains sharing suppliers and customers reflected in a network of relationships.

Within this context firms buyers configure their supply relationships based on their perception of supply risk. Risk is managed by either increasing trust or commitment or by increasing the number of suppliers. Increasing trust and commitment facilitates collaboration and reduces the propensity for a supplier to exit the relationship. Conversely, increasing the number of suppliers reduces dependency and increases the ease of making alternative supply arrangements.

The emergent network of relationships is dynamic and complex, and due in no small part to the influence of inventory management practices, tightly coupled. This critical organization of the network describes a system that contrary to existing supply chain conceptualisation exists far from equilibrium, requiring a different more appropriate theoretical lens through which to view them.

This thesis adopts a Complex Adaptive Systems (CAS) perspective to position supply networks as tightly coupled complex systems which according to Normal Accident Theory (NAT) are vulnerable to disruptions as a consequence of normal operations. The consequential boundless and emergent nature of supply networks makes them difficult to research using traditional empirical methods, instead this research builds a generalised supply network agent based computer model, allowing network constituents (agents) to take autonomous parallel action reflecting the true emergent nature of supply networks.

This thesis uses the results from a series of carefully designed computer experiments to elucidate how supply networks respond to a variety of market structures and permitted agent behaviours. Market structures define the vertical (between tier) and horizontal (within tier) levels of price differentiation. Within each structure agents are permitted to autonomously modify their prices (constrained by market structure) and collaborate by sharing demand information.

By examining how supply networks respond to different permitted agent behaviours in a range of market structures this thesis makes 4 contributions. Firstly, it extends NAT by incorporating the adaptive nature of supply network constituents. Secondly it extends supply chain management by specifying supply networks as dynamic not static phenomena. Thirdly it extends supply chain risk management through developing an understanding of the impact different permitted behaviour combinations on the networks vulnerability to disruptions in the context of normal operations. Finally by developing the understanding how normal operations impact a supply networks vulnerability to disruptions it informs the practice of supply chain risk management.

Keywords:

Complex adaptive systems, normal accident theory, agent based modelling, Supply chain management, supply chain risk

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LIST OF ABBREVIATIONS

ABM	Agent Based Modelling
AHP	Analytical Hierarchy Process
CAS	Complex adaptive system
CoV	Coefficient of Variation
CST	Complex Systems Theory
DEA	Data Envelopment Analysis
EOQ	Economic Order Quantity
HRO	High Reliability Organisation
HRT	High Reliability Theory
IMP Group	Industrial Marketing and Purchasing Group
NAT	Normal Accident Theory
ODD	Overview, Design Concepts, and Design Details
SET	Social Exchange Theory
TCE	Transaction Cost Economics

1 Introduction

Forethought we may have, undoubtedly, but not foresight.

- *Napoleon Bonaparte*

This chapter commences by setting out the motivation for this research through various illustrations of connectivity between supply chains and how this influences the propagation of disruptions across a supply network. The chapter then formalises the purpose of the research via a problem statement before concluding by outlining the structure of the remaining thesis.

1.1 The Unpredictable World

The world is an unpredictable place and globalisation with its relaxation of international boundaries has only served to emphasise the vulnerability of extended supply chains (Barry, 2004a; Peck, 2005; Sheffi, 2005).

The consequences of a small thunderstorm in Albuquerque in 2000 have been widely reported (Sheffi, 2005; Norrman and Jansson, 2004). This resulted in a lightning strike at the Philips production facility, and although the resultant fire was small, it contaminated a batch of computer chips being manufactured for a new generation of mobile phones. Principally, this production batch was destined for Nokia and Ericsson.

Both Nokia and Ericsson had diligently considered such a risk and both felt that they had developed an appropriate relationship with Philips to ensure they would be notified of any disruption to supply immediately. Philips did indeed inform both organisations of the fire; however, their responses were noticeably different.

Ericsson was content to manage the disruption from their headquarters in Sweden, whilst in contrast, Nokia dispatched a team of engineers and specialists to verify the significance of the fire and provide recovery assistance to Philips. It quickly became apparent to the Nokia team that the fire had also contaminated the clean room and as a result presented a much bigger risk of disruption in supply than had initially been realised. Through their quick response Nokia were able to secure capacity at other Philips sites and establish alternative supplies from other organisations. Through such a resilient design process Nokia were able to substitute the Philips chips with suitable alternatives.

Ericsson however, did not realise the significance of the fire until much later and were not able to secure alternative supplies, partly because these had already been secured by Nokia and partly because their design could not accept alternatives.

The consequence of the different responses to this disruption was that Nokia increased their market share by 3%, whilst Ericsson suffered significant losses ($430M -$570M) and a year later merged with Sony (Sheffi, 2005, pp.8-9).

Although well-rehearsed in the literature, the Philips Nokia Ericsson case is far from isolated. Sheffi (2005) also reported the consequences of Hurricane Mitch in 2001, which decimated banana plantations in the Bahamas. Both Dole and Chiquita had plantations that were badly affected. The fortunes of these two organisations can be differentiated on the basis of the supply chain strategy each adopted. In the case of Chiquita, the strategy to have multiple plantations in different geographical territories meant that their supply chain was robust. In contrast, Dole had designed their supply chain to maximise efficiency and relied on a single geographical source of supply, thereby rendering their supply chain efficient but vulnerable.

The disruptions described above illuminate two important aspects of supply networks; the first case shows how changes in one supply chain can affect other supply chains that share customers or suppliers, and the second case illustrates how the impact of disruptions can be dissipated through diversity.

High impact supply chain disruptions are not merely restricted to exogenous events such as natural disasters. Many organisations have been forced to announce reduced revenues, increased costs and decreasing profits as a consequence of endogenous operational difficulties.

The extant research uses these and other case studies to characterise disturbances and disruption of sources as either endogenous or exogenous to a particular supply chain as defined by a focal firm. This has resulted in widely accepted risk mitigation frameworks which neglect the interdependencies between supply chains (Anna et al., 2005; Arnold et al., 2010b; Chopra and Sodhi, 2004; 2004; Schipmann and Qaim, 2011; Zsidisin et al., 2004). Endogenous disturbances are framed by inventory management and capacity planning strategies that are designed to contain the disruption within a supply chain (Manuj and Mentzer, 2008; Zsidisin et al., 2008), whilst exogenous disruption descriptions lack detailed consideration of the pathways along which the generated disturbances can flow (Craighead et al., 2007b; Greening and Rutherford, 2011; 2011b; Bode et al., 2011; Hallikas and Virolainen, 2004).

1.2 Disturbances and Disruptions

Throughout this thesis the terms ‘disturbances’ and ‘disruptions’ are used to describe specific circumstances; therefore for the purposes of clarity, definitions for these two terms are provided below:

Disturbances refer to changes in flows or relationships where the consequences require no structural changes to the network of relationships that describe a supply network. In other words, a disturbance is contained by existing strategies or processes.

Disruptions are unanticipated changes in flow or relationships that require the re-organisation of flows and relationships beyond those anticipated or designed. In other words, the changes have a structural impact beyond any design or intent.

These definitions find broad support in the literature on normal accident theory (NAT) and complex adaptive systems (CASs), and these are considered in Chapter 2. However, the purpose of illustration, the definitions provided above can alternatively be developed from these two theoretical perspectives.

NAT takes a technological perspective to position failures and their impact on four levels, failures that relate to: 1) an individual part; 2) a unit consisting of parts; 3) a subsystem; or 4) the system itself. In supply network terms: a part equates to a firm, a unit to a dyad, a subsystem to a supply chain and a system to a supply network. NAT expressly dismisses failures at levels 1 and 2 unless they result in failures at levels 3 and 4 (Perrow, 1999, pp.64-65).

Similarly, CAS theory posits that emergence is a consequence of the interactions that occur constantly between organisations but occasionally structures undergo re-organisation when small and normally contained disturbances combine with other disturbances to overwhelm the extant structure of relationships and consequently redefine the network (Varga et al., 2009; Pathak et al., 2007a; Choi et al., 2001a).

These theoretical perspectives are discussed in much more detail in Chapter 2.

1.3 Problem Statement and Contributions

Much of supply chain management theory and practice balances process risk with performance by trading inventory for shared information anchored in collaborative relationships (Wilding and Humphries, 2006; Tsai et al., 2012; Juettner and Maklan, 2011; Wagner et al., 2011; Visser, 2010; Datta and Christopher, 2011a). Inventory can be minimised in a supply chain by sharing demand information, thereby reducing the uncertainty parameter that is key in determining the levels of inventory buffers. However, this framing neglects the low probability of disturbances in supply chains propagating beyond the assumed boundaries.

The network perspective exposes the risk associated with the connectedness of the supply chains. It can be argued that inventory minimisation practices increases the coupling of a network, thereby increasing the likelihood of disturbances propagating across supply chains that share suppliers and customers, an argument framed by NAT (Perrow, 1999).

The NAT perspective frames systems, a generalised description, such that normal process disturbances can propagate along dependency pathways to become coincident. In supply chain terms this presents the possibility of breaching a particular firm’s inventory and capacity mitigation strategies, which results in disruptions that can only be accommodated through the structural re-organisation of buyer/supplier relationships.

Despite this argument that process risk mitigation strategies may combine with inventory management strategies to develop network risk, there is surprisingly little literature that extends the supply chain concept to a supply network. This may be because theory development regarding supply networks faces significant barriers: the boundaries to networks are difficult to establish, the phenomena of interest is dynamic, and access to real world data is difficult (Choi et al., 2001a; Harland et al., 2001; Knight et al., 2005; Richard Lamming, Thomas Johnsen,Jurong Zheng and Christine Harland, 2000; Choi and Wu, 2009).

Whilst the case for considering how disturbances can migrate across supply chain boundaries through shared connections has been made, the role of competitive action in disturbing the patterns of supply and demand cannot be neglected. Particular demand for a product can be distributed across a set of potential suppliers according to the attractiveness of the suppliers to the buyers. An inevitable consequence of this is the reaction of those less attractive suppliers to their situation, as they may then act in ways to increase their attractiveness (Marshall , 1930).

The interaction between structure and individual firm action can be broadly parameterised as the supply strategy, in which suppliers are preferenced and many suppliers are selected, and a competitive strategy. The combined effect of these strategies defines the supply network structure and the flow of resources (material and cash) across it.

Supplier attractiveness has been the subject of extensive research since the 1960s and can be broadly categorised according to five supplier attributes: delivery, quality, price, flexibility and stability (Weber et al., 1991; Dempsey, 1978).

In view of the extant knowledge and its reliance on the essentially static structures of a supply chain defined by a focal firm, the purpose of this research is to address the following central question:

> *What is the impact of network structures and behaviours (price competition and collaboration) on a network's vulnerability to disruptions resulting from normal supply chain operations in both open and closed markets?*

The research sets out to make two contributions to the existing literature. Firstly, the research addresses the disruptive impact of normal operations as a result of network complexity and the coupling induced by normal supply chain practice. In practical terms this enriched understanding should allow managers to better quantify the potential for supply chain disruptions and to use this to inform improved tactical and strategic decisions framed by purchasing, horizontal collaboration, and relationship management.

Secondly, the research examines the interactions between collaborative and competitive forces across a network structure. In particular, the research seeks to understand how individual firm's actions are informed by their context, and how these actions combine with other firm's actions to generate new contexts. In practical terms this will deepen an organisation's understanding of how behaviours designed to secure the mitigation of supply risk may or may not, depending on context, achieve their desired outcomes. By understanding why risk mitigation strategies and tactics underperform it may then be possible for managers to design more robust risk mitigation approaches that more accurately reflect network dynamics.

1.4 Thesis Structure

The remainder of this thesis is organised as shown in Figure 1—1.

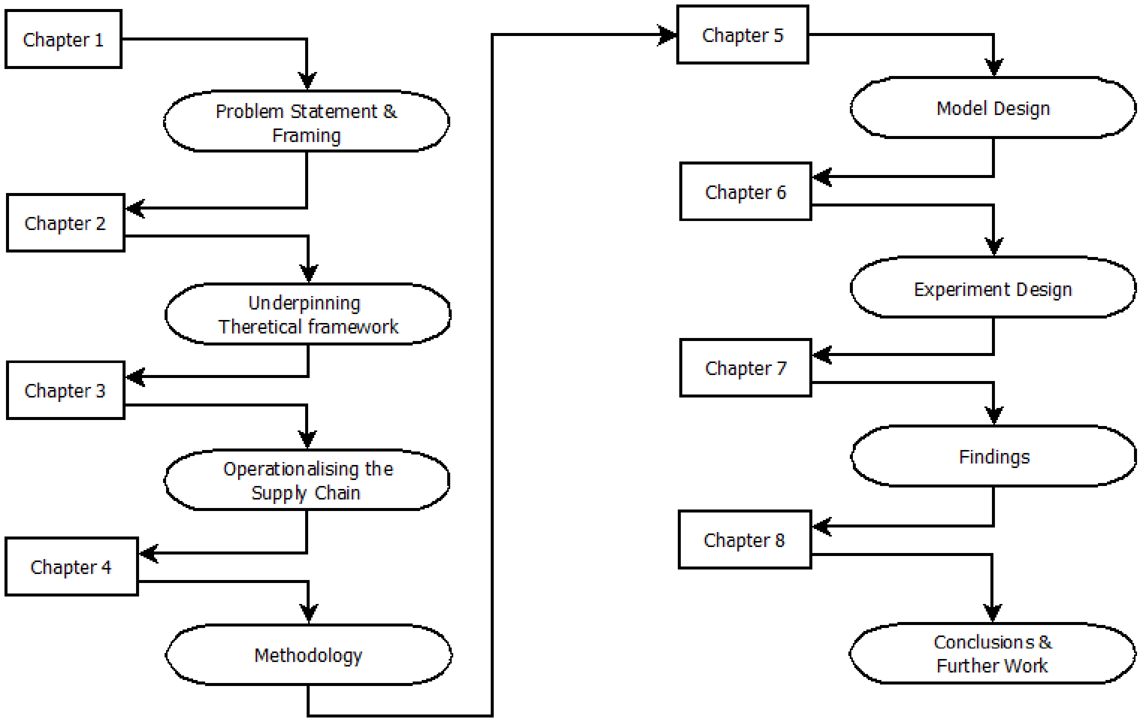


Figure 1—1: Schematic of the thesis structure

Chapter 1 introduces the problem addressed by the thesis and the core concepts used in defining the problem before concluding with a clear problem statement, research question and statement of intended contributions to knowledge and practice.

Chapter 2 critically reviews the underpinning literature that frames the problem statement and uses the analysis to identify gaps in the extant knowledge before developing a theoretical framework in which to anchor the research.

Chapter 3 critically considers the extant literature which describes the operationalisation of the supply chain and how organisations behave within this context.

Chapter 4 describes my philosophical position in relation to the research into similar phenomena conducted by other academics, before using this to develop rational arguments in support of the selected methodology in light of the various alternatives.

Chapter 5 describes the agent based modelling (ABM) developed to address the research question and to be reflective of my philosophical position.

Chapter 6 describes the logical and systematic development of the experiments applied to the ABM simulation.

Chapter 7 describes the procedures for analysing the results of the experiments and reports the results in the context of the research question with the intention of developing the arguments linking the constructs to develop new theory relating to NAT, supported by the evidence of the experiments.

Chapter 8 concludes the research and places the findings in the context of the existing theory, identifying the contributions of this work to theory and practice, before developing arguments in support of further work.

2 Underpinning Theory

The previous chapter, in constructing the problem statement, highlighted how the autonomous decisions of buyers and sellers determines the structure of a network comprised of adjacent supply chains connected through shared suppliers and customers.

The foundation of the supply chain conceptualisation is the focal firm which forms dyadic relationships with other firms. Dyads can then be connected to develop pathways of material flow from raw materials to consumption. It is the perspective of the focal firm that differentiates dyads and supply chains from supply networks which have no focal firms but describe a higher level system of embedded supply chains connected by shared customers and suppliers.

The selection of dyadic partners by buying organisations is an autonomous process, with contextually preferenced selection criteria intended to advantageously position the focal firm. The aggregation of multitudinous firms acting autonomously describes a CAS that defines a network structure providing pathways along which both intended flows of material and unintended disturbances travel. Generally, these structures provide the means by which disturbances are dissipated, but they can also permit pathways to develop coincidences of concentrated disturbances.

The following sections will consider in particular the extant knowledge relating to the negative consequences of coincidental events (NAT and high reliability theory, HRT), and the agency aspects of firm relationships (CAS) with the purpose of developing a theoretical framework that accommodates the connectivity of supply chains and their adaptive constituents.

2.1 Normal Accident Theory

Charles Perrow (1999) is generally considered to be the architect of NAT which was developed through the examination of the causes of accidents in complex systems. Perrow defined accidents as:

> *"….an accident is a failure in a subsystem or the system as a whole that damages more than one unit and in doing so disrupts the ongoing or future output of the system"* (Perrow, 1999, p.66)

Perrow also provided clarity regarding what constitutes a system, which he defined on four levels: parts, units, subsystems and systems. A part is the smallest part of a subsystem that can be identified when analysing an accident; a component is a collection of parts that are interrelated; a subsystem is a complexion of units; and a system is comprised of subsystems units and parts (Perrow, 1999). It is not difficult to draw from this definition that Perrow was largely interested in technical logical systems, although implicit in his analysis is the interaction between humans and technology.

In supply network terms, and in the particular context of this thesis, a part is a firm, a unit is an alliance or dyad, a subsystem is a supply chain of connected dyads, and the system is a collection of connected supply chains.

Perrow's (1999) theory was developed following analysis of the circumstances that surrounded the Three Mile Island nuclear disaster. The chain of events that led to a partial nuclear meltdown on 28th March 1979 was comprised of a series of failures of small parts, which caused a number of interrelated unit failures and resulted in the failure of subsystems and ultimately the system. However, the significance of this chain of events is anchored in the analysis of events taking place in other nuclear power stations. Perrow (1999, pp.32-59) found that almost all the power stations examined experienced similar failings of parts and units, leading him to conclude that had these failures occurred in a different sequence then they would have generated different dependency related failings at the system and subsystem levels. It is this analysis that defines a normal accident as one which will have high impact, low specific probability but very high general probability. In other words, the disaster of Three Mile Island was an inevitable and unavoidable consequence of small failures that triggered other failures resulting in a collapse of subsystem and system performance.

Perrow's work exposed two physical dimensions that relate to a system's vulnerability to these normal accidents: complexity and tight coupling (Perrow, 1999, pp.72-100). Perrow developed his conceptualisation of complexity from an engineering perspective, drawing upon an engineering definition of common-mode function which highlights the context whereby a part or unit serves more than one other part or unit; the implication being that if the focal part or unit fails then it will impact the operation of more than one other unit. If a system comprising many such connections traceability cannot be guaranteed, and in the event of operations or functions that transgress expected levels of performance, then the system takes on new characteristics not previously defined and not easily understandable to the operator. Formally, Perrow defined complex interactions as:

> *"Interactions…… Of unfamiliar sequences or unplanned and unexpected sequences and either not visible or not immediately comprehensible."*
> (Perrow, 1999, p.78)

The following sections consider the related dimensions of complexity and coupling within the framework of NAT.

2.1.1 Complexity

From a supply chain perspective, firms that share suppliers and customers represent nodes in a network where changes will impact on more than one organisation. Perrow refers to these as common modes (Perrow, 1999, pp.7273), and their significance can be found when comparing supply networks with supply chains.

The number of shared suppliers and customers (common modes) within a supply chain is limited by the perspective of the focal company. In particular, the supply chain is defined by a singularity or point of concentration, and in contrast, no such constraint exists within a supply network. As a consequence, a network has a much wider range of possible configurations compared to a network. Within a network firms react to their context, with their actions designed to create advantages for them and disadvantage for their competitors. Furthermore, as will be discussed in later chapters, it is generally accepted that firms operate under conditions of bounded rationality, in other words they are limited in their access to complete information. This inevitably limits their contextual awareness and results in imperfect decisions and perpetual adjustment.

Table 2-1is taken from (Perrow, 1999) and provides a basis on which complex and linear systems can be differentiated, thereby providing a definition of complexity as perceived by NAT.

Table 2-1: Differences between complex and linear systems

Complex systems	Linear Systems
Tight spacing of equipment	Equipment spread out
Proximate production steps	Segregated production steps
Many common mode connections of components not in production sequence	Common mode connections limited to power supply and environment
Limited isolation failed components	Easy isolation failed components
Personnel specialisation limits awareness of interdependencies	Less personnel specialisation
Limited substitution supplies and materials	Extensive substitution supplies and materials
Unfamiliar or contended feedback loops	Few unfamiliar or unintended feedback loops
Many control parameters within potential interactions	Control parameters view, direct, and segregated
Indirect or inferential information sources	Direct online information sources
Limited understanding of some processes	Extensive understanding of all processes

Source: (Perrow, 1999)

Within this definition of complexity it is easy to position supply networks as being complex based on: their many common-mode connections describing shared suppliers and customers; limited isolation of failed parts of the network; specialisation combining with bounded rationality to limit awareness of context; specialisation limiting substitution of suppliers; and supply/demand and collaboration processes developing feedback loops.

However, complexity is only one of the dimensions that define a system as being vulnerable to normal accidents; therefore, the next section will consider how coupling is defined in the context of supply networks.

2.1.2 Coupling

Tight coupling assumes a general definition that is widely understood, inferring little or no slack together with the absence of buffers between parts, units or in the case of supply chains, supply firms. (Perrow, 1999) is particularly concerned with the impact of tight coupling on a system's ability to recover from failure, and suggested that in loosely coupled systems alternative arrangements and interventions can be more easily implemented than in tightly coupled systems, which must be designed with some anticipation of disturbances that are likely to occur. In supply chain terms it is commonplace to anticipate supply disturbances in supply/demand fluctuations, and these are used to define inventory buffers yielding some flexibility in what would otherwise be an extremely tightly coupled system of inter-firm relationships.

Table 2-2 is taken from (Perrow, 1999) and is useful in positioning supply networks as tightly coupled.

Table 2-2: Differences between tight and loose coupling of supply networks

Tight coupling	Loose coupling
Delays in processing not possible	Processing delays possible
Invariant sequences	Order of sequences can be changed
Only one method to achieve goals	Alternative methods available
Little slack possible in supplies, equipment and personnel	Slacking resources possible
Buffers and redundancies are designed in	Buffers and redundancies fortuitously available
Substitution of supplies equipment and personnel limited, and designed in	Substitutions fortuitously available

Source: (Perrow, 1999)

This consideration of coupling demands a deeper analysis of the degree to which supply networks are tightly coupled. If supply networks have no inventory or production capacity buffers it would not be difficult to argue that a supply network is indeed tightly coupled, particularly as supplier switching would not be a possibility, either by design or imperative. However, much of supply chain management is aimed at the design of appropriate buffers to manage uncertainty in either supply or demand.

The supply chain concept embeds supply uncertainty in the unpredictability of the production processes and customer demand. It explicitly excludes the possibility of disturbances being created in adjacent supply chains and migrating across supply chain boundaries into adjacent supply chains through shared suppliers and customers. Logically, the incomplete conceptualisation of the supply chain may well result in designs that result in networks that are in fact more tightly coupled than originally intended and this results in ambiguity regarding how tightly coupled a supply network that emerges from disparate supply chain designs actually is.

The classification of supply networks as tightly coupled is further complicated by their constituents possessing adaptive capabilities (Hopkins, 2001) suggesting that the degree of coupling can flex although it is clearly the intention of every firm to minimise their inventory as much as possible without sacrificing competitiveness.

Table 2-3 maps (Perrow, 1999) definitions of complexity and coupling against the supply chain context in order to illustrate that supply chains are tightly coupled complex systems.

Table 2-3: Definitions of complexity and coupling within the supply chain context

NAT construct	NAT Characteristic	Supply Network Context
Complexity	Limited isolation failed components	Specialisation, dependency and investment in transaction specific assets combines with supply economic imperative to restrict ability to isolate suppliers
	Personnel specialisation limits awareness of interdependencies	Specialisation of the firm and risk sharing principles means that organisations supply to multiple markets restricting visibility of interdependencies
	Limited substitution supplies and materials	In anything other than the perfect market substitution is limited
	Unfamiliar or contended feedback loops	Collaboration feeds dependency; supply feeds demand
	Many control parameters within potential interactions	Relationship management, asset specific investments, product development, strategic intent etc.
Coupling	Delays in processing not possible	Upstream and downstream processes highly dependent on each other
	Invariant sequences	Sequences follow hard designs
	Little slack possible in supplies, equipment and personnel	Slack in form of redundancy is expensive (capacity and do the trick)
	Buffers and redundancies are designed in	Inventory management principles
	Substitution of supplies equipment and personnel limited, and designed in	Dependencies established through collaboration and strategic alliances

2.1.3 National Accident Theory and High Reliability Theory

As previously mentioned, Perrow's (1999) seminal work draws mainly on failures within technological systems, in other words systems that have no inherent adaptation and in the absence of any part or unit failure perform predictably. The constructs used to define NAT have a broader application, and complexity has found tenancy in organisational theory (Morel and Ramanujam, 1999) and the social sciences (Bonabeau, 2007; Burgelman and Grove, 2007b; Li et al., 2010; Prigogine, 1997), whilst the definition of coupling clearly has relevance to the inventory management aspect of supply chain management (Skilton and Robinson, 2009; Speier et al.; Yang and Yang, 2010b). Organisations and supply chains are constructed from parts and units that have adaptive capabilities, in other words they can autonomously redefine their purpose, and role within the broader system. Furthermore, as subsequent chapters will highlight, their imperfect vision of what comprises a system results in adaptation focused on local efficiencies, which are not necessarily aligned to system efficiencies or system operation.

In keeping with the adaptive nature of organisations, HRT is generally positioned as complementary to NAT and not necessarily as an alternative (La Porte and Rochlin, 1994; Leveson et al., 2009; Rijpma, 1997; Shrivastava et al., 2009b). The premise of HRT is that given an expectation that failures in the form of Perrow's normal accident will occur, these can be mitigated by mindfulness and preparedness. Weick (2007) describes mindfulness in terms of five principles: 1) preoccupation with failure; 2) reluctance to simplify; 3) sensitivity in operations; 4) commitment to resilience; and 5) deference to expertise. However, Rijpma (1997) has highlighted that these principles can present a tension with NAT in the context of adaptive organisations:

> *"On the one hand, redundancy increases the amount of information generated; the anticipation of a higher number of complex interactions is improved when conceptual slack is maintained; and learning may reduce the level of complexity. On the other hand, redundancy increases the level of complexity by inducing ambiguity, opaqueness and the occurrence of simultaneous failures; conceptual slack may create confusion; and, finally, decision premises increase the level of tight-coupling."* (Rijpma, 1997)

This seems to suggest that perhaps the greatest mitigating attribute of a high reliability organisation (HRO) is the ability to contextually and perpetually balance the mitigating actions with their potentially negative impact on vulnerability to normal accidents. Others have pointed out that HROs adopt different stances in different contexts, thereby allowing complexity and coupling to develop where necessary but moving swiftly to re-organise when faced with a 'normal accident'.

Although much is shared between the two theoretical positions discussion in recent years has become somewhat polarised, with normal accident theorists accusing high reliability theorists of selecting the underpinning of their theory with data collected from organisations that do not experience normal accidents (Hopkins, 2001). Employing this argument normal accident theorists position such companies as not existing in complex tightly coupled circumstances. The converse argument clearly has equal tenancy and consequently this discussion is far from resolved.

2.1.4 Summary

Perhaps because of Perrow's emphasis on technological systems, or maybe because of the immaturity of supply network theory, or even due to a combination of both these factors, there has been surprisingly little literature generated relating supply networks to NAT (Skilton and Robinson, 2009; Speier et al.; Yang and Yang, 2010b; Wagner and Neshat, 2012). This is despite the evidence that supply chains are indeed interconnected with adjacent supply chains through shared suppliers and customers, thereby developing a complex tightly coupled network.

The underpinning assumption of this thesis in the application of NAT to supply networks is that routine processes combine with processes designed to ensure competitiveness are articulated by focal firms and connected organisations in ways that maintain the possibility of disturbances coinciding, and which periodically overpower the firms when such a coincident occurs.

The normal process of adaptation, some of which anticipates disturbances, routinely executed by firms within a network can logically attenuate or amplify a system's vulnerability to coincident disturbances. Firms that consistently know how to respond appropriately to a network risk context could alternatively be framed as high reliability organisations.

The theoretical foundation of NAT and the behaviour described above is found in CAS theory which is the main focus of the next section.

2.2 Complex Adaptive Systems and Supply Networks

The differentiation between networks and chains centres on whether or not any focal firm is identified or used to define an inter-firm organisational structure. The initial conceptualisation of supply networks was developed from the supply chain and described the serial linking of dyadic relationships where each node in the chain linked to a downstream and upstream partnering node. Each node had one connection providing the flow of materials in and one providing the flow of materials out (Harland et al., 2001; Harland et al., 2004). This concept was extended so that each node could be connected to more than one node, thus reflecting the flow of materials into a focal node defined by the production of a product or group of products which required multiple flows in and potentially out (Harland et al., 2001; Harland et al., 2004). However, this conceptualisation still had a focal firm at its centre.

Adopting the focal firm perspective proved useful in that it allowed the deterministic/stochastic description of relationships. The simplicity, and to some extent clarity, provided by this approach is gained by assuming a static relationship formulation. The limitations of adopting such linear deterministic perspectives to explain supply chain behaviour over the medium to long term have been identified by a number of authors (Choi et al., 2001a; Bechtel and Jayaram, 1997). The essence of these limitations are the constrained choice embedded in a supply chain conceptualisation and that firms cannot create new relationships with firms that are outside the extant supply chain without re-defining the chain, thereby limiting the incorporation of competitive responses and actions designed to secure supply at times of crisis.

More recently researchers have accepted that this represents a simplistic and static description of a supply network, (Harland, 1996) and have drawn upon the work of the Industrial Marketing and Purchasing (IMP) Group which described networks in a broader context of connected supply chains not defined by the focal firm (Gadde and Hakansson, 1993; Hakansson, 1980; Anderson et al., 1994; Ford and Håkansson, 2006)

(Gadde and Hakansson, 1993; Hakansson, 1980; Anderson et al., 1994; Ford and Håkansson, 2006)

. The evolution of the supply network is summarised in Figure 2—1.

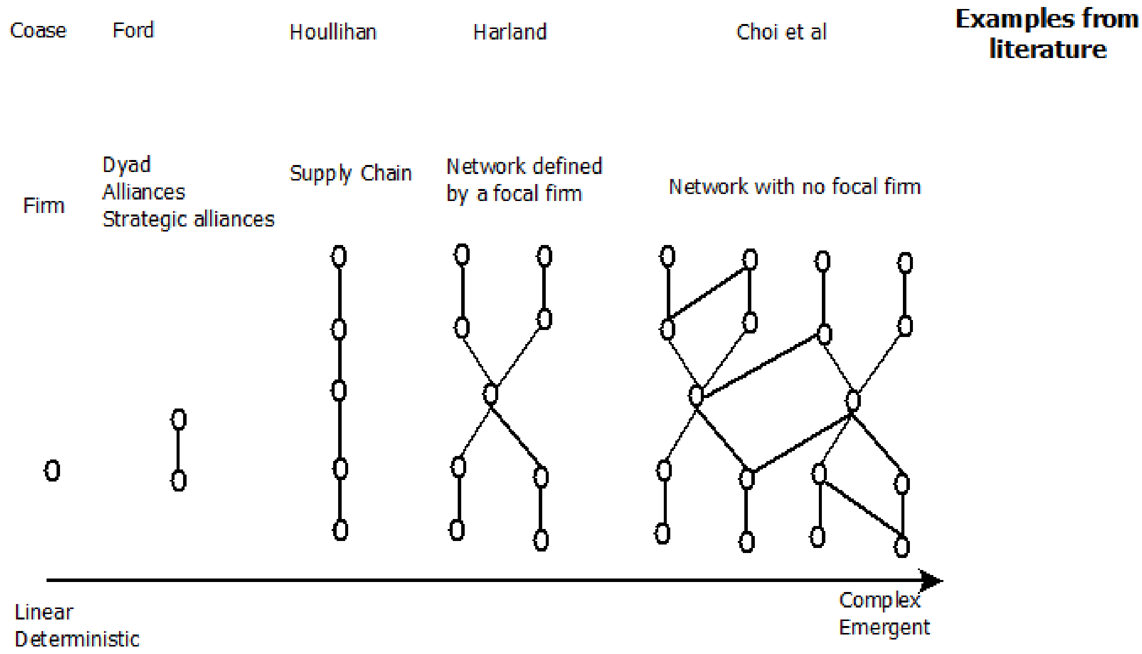


Figure 2—1: Evolution of the supply network

The contemporaneous description of supply networks is generally accepted as:

> Supply networks are nested within wider interorganization networks and consist of interconnected identities whose primary purpose is the procurement, use and transformation of resources to provide packages of goods and services. Supply networks therefore essentially consist of a set of interconnected supply chains, encompassing both upstream and downstream relationships. (Harland et al., 2004)

Harland (2001) and others (Cantu et al., 2012; Tuominen et al., 2004) have used the above conceptualisation to build a description of competencies and roles within networks. These reflect the dynamism of the network and often refer to participant firms positioning within, and managing their context. Conditions of bonded rationality result in an absence of synchronicity across the network perpetuating dynamic behaviour, which in turn redefines the macro level description thereby driving the constituents at the firm level to adapt.

Choi (2001a) conceptualised supply networks as CASs, arguing that adaptation plays an essential role in defining the structure of a network. If firms can, and do, select/deselect the firms with whom they trade then the supply chains can be redefined through the exclusion or inclusion of new trading partners, if this process is, as argued by Choi (2001a), an essential characteristic of how firms behave then the static supply network form cannot persist in time as it does not include participants not already connected to the focal company. The supply network as described by Choi (2001a) incorporates the micro-level coordination described by Harland (2001), but extends the consequences of this into the emergent network. The network form resists formal coordination, instead it is an emergent consequence of the dyadic/supply chain coordination of its participants, a phenomenon described as co-evolution (Choi et al., 2001a; Kim et al., 2011) .

Morel (1999) laid the foundation for viewing organisations through the lens of complex system theory (CST) by using fundamental constructs to explain phenomena such as dynamic change, adaptation, and evolution (Stacey, 1995; Eisenhardt and Brown, 1998).

At a high level, complex systems can be defined by large numbers of interacting elements linked by feedback and feed forward mechanisms whose activity results in emergent characteristics that defy linear deterministic descriptions. Importantly, these emergent patterns are independently observable and therefore verifiable.

2.2.1 Self-Organisation

The basic and perhaps most controversial elemental behaviour of complex systems is self-organisation. This describes a process where devoid of any grand design/designer, a system evolves to become more organised. This has been positioned by some as a breach of the second law of thermodynamics, which states that a system will tend to become more disorganised, or at least more dissipative, in its journey towards equilibrium. The tendency of a system to gravitate towards maximum entropy is supported by physics, and seemingly contradicted by social systems. However, it remains unclear as to why a law describing physical systems with no conscious adaptive capability should be appropriate to systems whose components can adapt to sate self-interest.

Within the complex systems paradigm, self-organisation is not limited simply to social systems, as it can be observed in physical systems. Bak (1999) illustrated one such physical system by describing grains of sand falling through an hour glass to form a solid cone, although if observed carefully, this cone experiences periodic re-organisation, what Bak called avalanches.

These observations expose two more fundamental characteristics of complex systems: punctuated equilibrium and self-organising criticality.

2.2.2 Self-Organising Criticality

Per Bak (1999) defines self-organised criticality as:

> ….. a state way out of balance where minor disturbances may lead to events, called avalanches, of all sizes. Most of the changes take place through catastrophic events rather than by following a smooth gradual path. The evolution to this very delicate state occurs without design from any outside agent. The state is established solely because of the dynamic interactions among individual elements of the system. (Bak, 1999)

Others have drawn on the second law of thermodynamics as a means of differentiating complex systems from linear systems, in that the former is susceptible to self-organising criticality and emergence. Essentially, the second law states that close systems will tend towards a state of equilibrium which is described by maximum entropy. In other words, closed systems will always reach a state of equilibrium, whilst open systems can exist in far from equilibrium states which are maintained by energy/resource inputs and outputs. If the system is sufficiently complex, i.e. populated with numerous interactions between the constituents of the system, then an open system will tend to self-organise criticality as opposed to moving towards the equilibrium (Prigogine, 1997).

Furthermore, whilst the supply chain conceptualisation is essentially a closed system (new firms are not permitted to join nor can any existing firm exit), network conceptualisation is of an open system, a justification given by some for its tendency towards self-organised criticality (Choi et al., 2001a; Burgelman and Grove, 2007b; Miller and Page, 2007; Surana et al., 2005), as opposed to an equilibrium of maximum entropy. This same phenomenon is used by Barabasi (2003) to explain the scale invariant formation of small worlds. By adopting a network description of the flow of materials from their raw state through to consumption, many more dynamics can be incorporated into the system, thereby allowing the constituent parts to dynamically organise in a number of different configurations. In addition, networks can be configured to allow new organisations to enter the system and challenge the incumbent organisations in terms of efficiencies (Prigogine, 1997). Thus it can be argued that a supply network is a much more open system conceptualisation, incorporating dynamics of organisation and permitting the entry and exit of organisational resources. These conditions define supply networks as complex systems existing far from their equilibriums (Prigogine, 1997) .

Per Bak's (1999) observation of the sand pile is an experiment that has been repeated by many and the avalanches of observed as grains of sand are added to the pile follow a distribution described by a power law:

Equation 2-1:

$$\boldsymbol{N(s) = S^{-\tau}}$$

Where $N(s)$ represent the number of events of characteristic S and τ is an exponent value. In the case of supply network disruptions, the equation could be used to describe the number of disruptions greater than a specified magnitude.

Self-organising criticality and the patterns of behaviour observed in such systems define complexity and differentiate complex systems from linear deterministic systems through the characteristics of openness, distance from equilibrium, and critical organisation.

2.2.3 Punctuated Equilibrium

Bak's (1999) sand pile metaphor can be extended through the observation that the avalanches interrupt periods of stasis, thereby highlighting the importance of criticality in determining the behaviour of complex systems. It is not possible to observe continuous changes in the sand pile structure, but the structure changes as a consequence of small or large avalanches, significant events that are discontinuous in their nature, as Bak observes:

> punctuated equilibrium is the idea that evolution occurs in spurts instead of following slow but steady path suggested by Darwin. Long periods of stasis with little activity in terms of extinctions or emergence of new species are interrupted by intermittent bursts of activity. (Bak, 1999)

Punctuated equilibrium is depicted in Figure 2—2 and has been observed in many systems, including economics (Brown and Eisenhardt, 1997) , nature (Bak, 1999) and even supply chains (Choi et al., 2001a; Friedl and Wagner, 2012). Significantly punctuated equilibrium can also been mapped using a power law distribution: the time interval between events that exceeds a given magnitude follows a power law distribution with the interval between larger events being greater than the interval between smaller events. However, it is important to highlight that this does not mean that a system having just experienced a large change will not experience a similar magnitude of change for a long period of time, just that the probability of a large change following the last change is smaller.

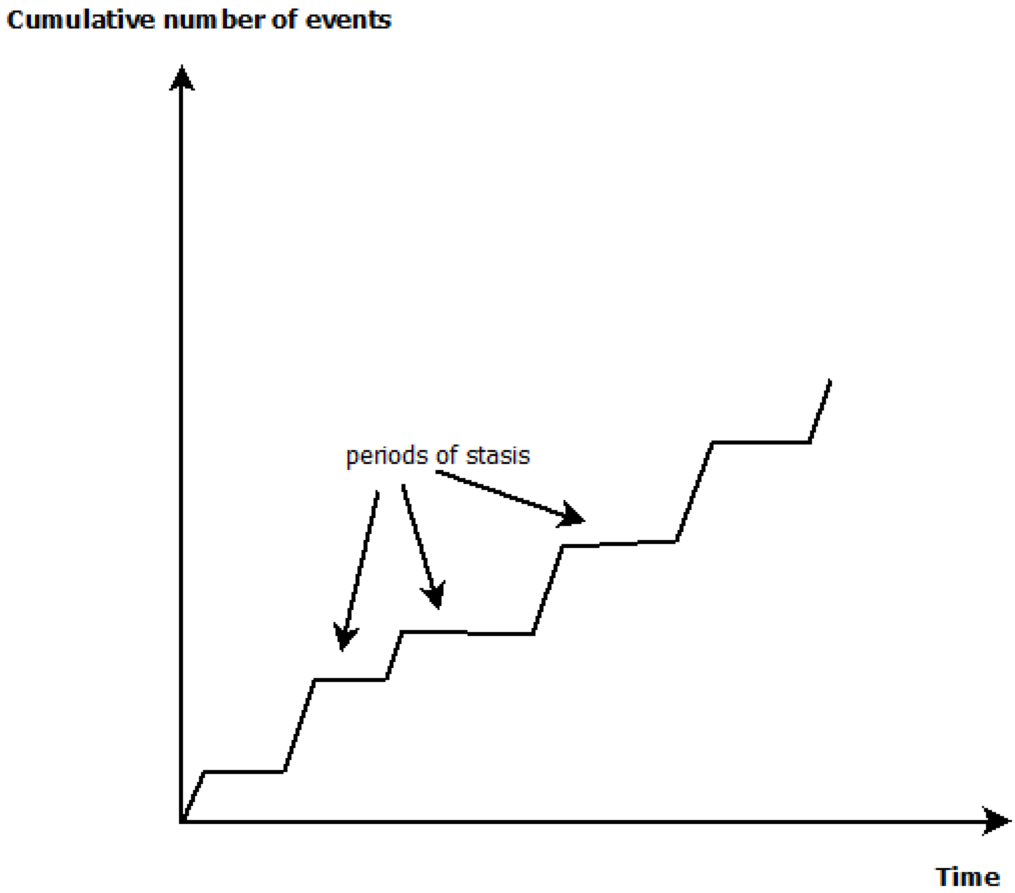


Figure 2—2: An example of punctuated equilibrium

Source:

2.2.4 Challenges to Complex System Theory

The major criticism of CST is that it is used mainly as an explanatory framework that yields little, if any, predictive power. Eric Bonabeau (2003) extolled the benefit of the CST perspective framed by significant constraints:

> *"The more complex the situation, more misleading intuition becomes. In a truly chaotic environment – where cause and effect no longer have a linear relationship - the last thing you want to do is try to apply pattems to it.*" (Bonabeau, 2003)

Systems that are irreducible are also complicated and critically organised, which results in emergence; non-linear outcomes whose specificity denies determinism and as such provides no conveniently traceable sequence of events.

Furthermore, it is undeniable that complexity lacks a robust definition (Bak, 1999); it is not easy to differentiate simple from complex and consequently identify the contexts in which the CST perspective offers greater insights than alternative approaches. To be specific, one of the more robust tests of complexity, the power law distribution of events, requires many observations to be made of a system under different initial conditions, which for many complex systems rules out the collection of real world data with which to validate theoretical frameworks (Bonabeau, 2003; Bonabeau and Krebs, 2002).

Emergence, by its very nature, defies traceability as causes are often disguised by complexity (Skilton and Robinson, 2009). Without the formal descriptions of cause and effect understanding is constrained simply to observations, which can only become robust when repeated over many initial conditions. The sensitivity of a complex system to its own unique history, which defines its initial conditions, precludes exact predictions. Instead we are driven towards identifying broad patterns that persist in a wide range of specific contexts.

In essence, the CST perspective requires placing aside the highly specific as simply one possibility amongst many and instead explores the space defined many possible outcomes from many similar initial conditions in order to identify patterns that can be generalised.

2.2.5 Complexity Summarised

Bak’s (1999) interest in complexity was triggered by the simple observation that a few simple rules can create complex and beautiful structures, although Bak was not the only one to make this observation.

Mandelbrot (Mandelbrot, 1963) studied the price variations of several commodities and found that if the probability of a price variation of a specified magnitude was regressed on the price variation, then in every case the resultant relationship could be described by a power law.

Power laws describing the distribution of events and punctuated equilibrium are a direct consequence of critical organisation, which positions them as a fundamental property of complex systems. It is a characteristic of a power law that within obvious boundaries the established relationships are scale invariant (Barabasi and Bonabeau, 2003), that is to say that the relationship is maintained for all values of the dependent and independent variables considered.

The systems described by Bak (1999) are largely, but not exclusively, physical systems devoid of social interactions. The incorporation of system constituents that can adapt or change their nature creates a special category of complex systems, which has assumed the mantel of CASs.

Whilst the conceptualisation of complex systems is useful in the description of criticality, itself a description of the systems adaptation to its context, it is incomplete in contexts whereby the systems constituents can also adapt to the environment defined by the system. Firm adaptation in response to changing patterns of risk, demand and supply, is a vital behavioural characteristic of supply networks. The next section will therefore consider the specific category of CASs in relation to supply networks.

2.2.6 Complex Adaptive Systems

Social systems theory can be described in in three waves: 1) structural functionalism; 2) general systems theory; and 3) CASs.

Structural functionalism assumes that entities cooperate to build stability through the establishment of macro norms. Entities assume goals related to their position, without agency, and seek cohesion without conflict. General systems theory emphasises that roles could represent systems within systems, and developed cybernetic principles to incorporate feedback and feed forward mechanisms into the system. Whilst not precluding autonomous actions of the system components, the system remained the level of analysis. CASs embraces general systems theory but permits autonomous behaviours cached in terms of bounded rationality which co-evolve with the environment they create.

In broad terms, the structure of a CAS develops complexity through its population of constituents, who interact according to local rules thereby denying any global control or design but permitting the autonomous re-specification of rules in order to achieve improved fitness for individuals within the system (Stacey, 2001; Pascale, 1999, p. 84). As such, a CAS incorporates all of the phenomena and constructs found in complex systems but permits adaptation.

Morel (1999) highlights a perceived weakness of the CAS paradigm:

> *"One weakness of CAS as a paradigm for understanding self-organisation is that the adaptive behaviour of the agents is an input, and the physics of the self-organisation is buried in the assumptions. Seen from the perspective of physics, self-organisation requires a mix of conditions like being out of equilibrium (Nicolis and Prigogine 1977), and the dynamic possibility of building new stable dynamic units made from the aggregation of several components. The adaptive nature of the agent is what a physicist would like to 'explain', not assume."* (Morel and Ramanujam, 1999)

The CAS perspective means that small disturbances to the system have unpredictable consequences because they are contingent on the state of all other constituent elements, which are determined by their unique history and the interactions that are destined to take place. That is not to say such systems are devoid of structure or patterns, simply that the patterns relate to the probability of new patterns emerging, patterns which defy specific definition, for example detailed descriptions of connections, but accept generalised descriptions such as levels of system connectivity. In this sense the application of CASs provides a useful lens through which to view organisational phenomena and has consequently gained traction in many of the organisational theory disciplines (Li et al., 2010; DeLaurentis and Ayyalasomayajula, 2009; Li et al., 2009; Nair et al., 2009; Burgelman and Grove, 2007a). In particular, some academics have adopted this perspective to examine the dynamic phenomena of supply networks, which are difficult to explain using the more traditional linear and deterministic supply chain conceptualisations.

The following section will explore the extant literature which uses the CAS perspective as a means through which to view supply networks and associated phenomena.

2.2.7 Supply Networks as Complex Adaptive Systems

Choi (2001a) presents the argument that a supply network should be considered from a CAS perspective because it is possible to identify self-organisation, co-evolution and emergent properties. Specifically, the emergent supply network is not designed by any organisation; rather it is a consequence of the many relationships that are formed across multiple supply chains, inevitability resulting in some supply chains sharing customers and suppliers. In an attempt to better their position within the network, focal organisations adapt to their environment with the sole purpose of changing it and in turn, these changes require other participants to respond to the changing environment. This perpetual cycle of adaptation perfectly describes co-evolution. The combination of self-organisation and co-evolution results in supply networks exhibiting emergent properties (Varga et al., 2009; Pathak et al., 2007a; Choi et al., 2001a; Li et al., 2009; Nair et al., 2009; Alawamleh and Popplewell, 2011; Kim, 2009).

Choi (2001a) provides a conceptual framework for a CAS which illustrates the interactions between firm (agent) behaviour, the environment created by these interactions, and emergent characteristics of the system (Figure 2—3).

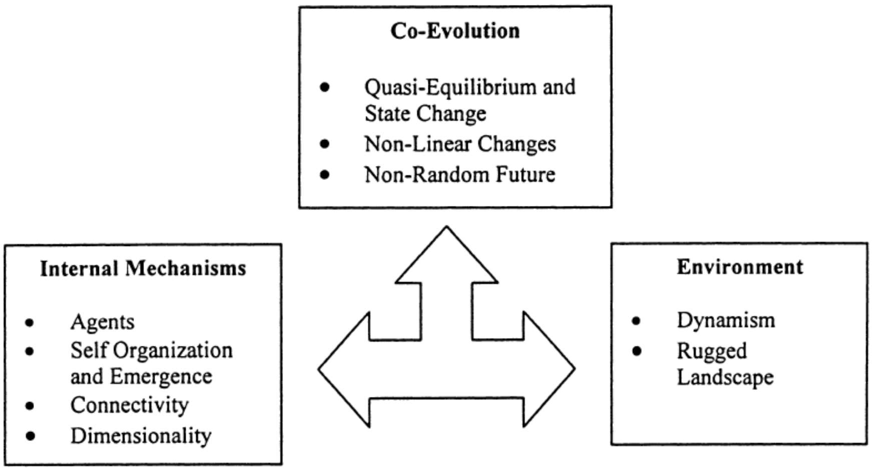


Figure 2—3: Supply chains as CASs

Source: (Dooley et al, xxxx)

Although Choi (2001a) does not have a particular scenario in mind, they posit that the connectivity of a supply network develops pathways through which disparate supply chains compete for resources. The level of competition and the availability of such resources clearly determine the degree to which the network relationships are susceptible to re-organisation.

The rules that govern agent behaviour, the resultant self-organisation, and high levels of connectivity, render the supply network difficult to control. Despite this, the attractiveness of imposing a level of predictability on a highly unpredictable system has resulted in organisations cooperating to develop common standards. This form of governance represents a coordinated attempt to reduce the dimensionality/degrees of freedom that exist within a supply network, although the ultimate goal of control remains elusive (Choi and Eboch, 1998).

The autonomous actions of firms are designed to achieve local optimisation, and often neglect the interdependencies between organisations, which may represent a more powerful driver of performance. For instance, the bullwhip effect (Forrester, 1961) can be interpreted as a consequence of autonomous locally optimised behaviour by supply chain participants. This was surely a major driver in the conceptualisation of supply chains and the subsequent trajectory of extending coordination beyond the constraints of a focal firm.

The combination of autonomous agent behaviour interacting with an environment defined by network participant behaviour results in co-evolution which is emergent and non-linear, yet not random (Bak, 1999; Miller and Page, 2007). In other words, the CAS perspective posits that despite the non-linearity the emergent dynamic supply network is likely to exhibit some patterns of structure.

This perspective is not dissimilar to that proposed by the IMP Group who, whilst not formalising their concepts with quite the same structure, argue that buyer supplier relationships are relational and incorporate reciprocity (Anderson et al., 1994; Ford et al., 1986; Hakansson and Persson, 2004). That is to say the actions of a buyer affect the actions of a supplier, which in turn affects the actions of the buyer. When this principle is extended to cover multiple connected dyads it is a small step to then recognise it as self-organisation, the consequences of which is the co-evolution of buyers and sellers. The IMP Group perspective is therefore closely aligned to the CAS perspective presented by Choi (2001a).

Both the CAS and IMP Group perspectives present a managerial challenge: the networks within which a firm exists cannot be designed or managed, yet they are a key determinant of a firm's action and its fortunes.

Moving beyond the conceptualisations of complexity theory has proved difficult, particularly in the social sciences as they must include adaptation (Morel and Ramanujam, 1999; Uzzi, 1997), and this is as true of supply networks as it is of other organisational forms.

The phase changes described by punctual equilibrium may explain how supply networks come to be re-organised: the adaptation of each agent to manageable disturbances determines how well a particular firm will be positioned to absorb the next wave of routine disturbance, which in themselves will have been shaped by the adaptive processes. Occasionally, a firm will find it necessary to redefine its relationships, and inevitably this will trigger a percolation of adaptations, some of which may also create disruptions/disturbances.

There is an inevitable logic that if the phenomenon of interest is the interaction of supply chains then the focal firm perspective, despite its useful insights into its operation in neo-equilibrium conditions, is inadequate (Li et al., 2010; DeLaurentis and Ayyalasomayajula, 2009; Li et al., 2009; Nair et al., 2009; Burgelman and Grove, 2007a). Conversely, the conceptualisation of overlapping supply chains as a network is difficult to anchor in empirical data due to the difficulty in defining the network and the collection of data across many organisations, often incorporating competitive dimensions. Notwithstanding the difficulty of collecting empirical data across networks, the conceptualisation of a supply network as a CAS remains attractive as it incorporates critical events requiring re-organisation of the system which the focal firm perspective cannot. Autonomous decisions taken in conditions of bounded rationality create context to which the participants respond. This perpetual cycle of adaptation results in self-organisation and co-evolution, and is framed by supply chain processes such as supplier selection (Dempsey; Dyer et al., 1998; Ellram, 1990; Monczka et al., 1998), design of supply strategy (Godsell et al., 2011; Krause and Ellram, 1997; Kraljic, 1983), inventory management (Emery and Marques, 2011; Nair and Vidal, 2011; Fawcett et al., 2010; Waters, 2003), supplier switching (Friedl and Wagner, 2012; Geiger et al., 2012; Wilson, 2012; Thomas Pfeiffer, 2010; Wagner and Friedl, 2007), risk analysis (Barry, 2004b; Blackhurst et al., 2008; Chopra and Sodhi, 2004a; Craighead et al., 2007a; Juttner, 2005; Khan and Burnes, 2007), and pricing (Marshall , 1930; Narasimhan et al., 2009; Williamson, 2003; Williamson, 1998; Williamson, 1992).

Much of the literature supporting the application of a complex systems theoretical lens to supply chains/networks is justified by the multitudinous connections between many supply chain member organisations (Choi and Krause, 2006). If supply chains do indeed behave as complex systems then it would be expected to find evidence of emergence and self-organisation (Choi et al., 2001a), particularly in the context of disruption which acts as a catalyst for re-organisation.

There is some evidence to suggest that supply networks do indeed operate as complex systems and are sufficiently tightly coupled for disruptive events to have extended reach within the network. The fuel protest of September 2000 (summarised by McKinnon (2006) in the UK resulted in approximately half the nation's petrol stations running out of fuel within two days of the protest starting (Marsden and Beecroft, 2002). Although the protest only lasted five days, it was estimated ‘that 10% of national output was lost during each of the last four days of the protest’ and this was despite the fact that road freight traffic was only reduced by between 10 and

12% (Hathaway, 2000). If this analysis is true then it suggests that the UK freight system, and by inference the supply chains contained therein, is much more tightly coupled than may first be imagined. The analysis of the UK fuel protests is very similar to the analysis of the events surrounding September 11, 2001 and Sheffi (2001) described the speed with which global supply chains began to collapse following the terrorist attack. Increased border controls meant that trucks were delayed at both the Canadian and Mexican borders. The closing of airspace to inbound traffic resulted in vital components not reaching production lines, an effect most acutely felt in the just-in-time environment of the automotive industry. Both these cases highlight the vulnerability of supply networks to disruptive events extraneous to the network itself; nevertheless, the impact of these disruptions can only propagate through a system at the observed speeds if that system contains many pathways and is tightly coupled.

It therefore appears that there is some evidence to suggest supply networks are indeed CASs, meaning they are, at least in the context of disruption, irreducible, emergent, and self-organising. Consequently, it can be argued that any approach to studying the phenomenon of disruptions in supply networks has to assume a network level of analysis and a CAS perspective.

The adoption of the CAS perspective as a lens through which network risk can be viewed clearly requires an understanding of agent (firm) behaviour, as this provides the mechanism by which networks are created, the consequential environment, and the interaction of an agent with the environment. The description of supply networks as CASs is summarised in Figure 2—4.

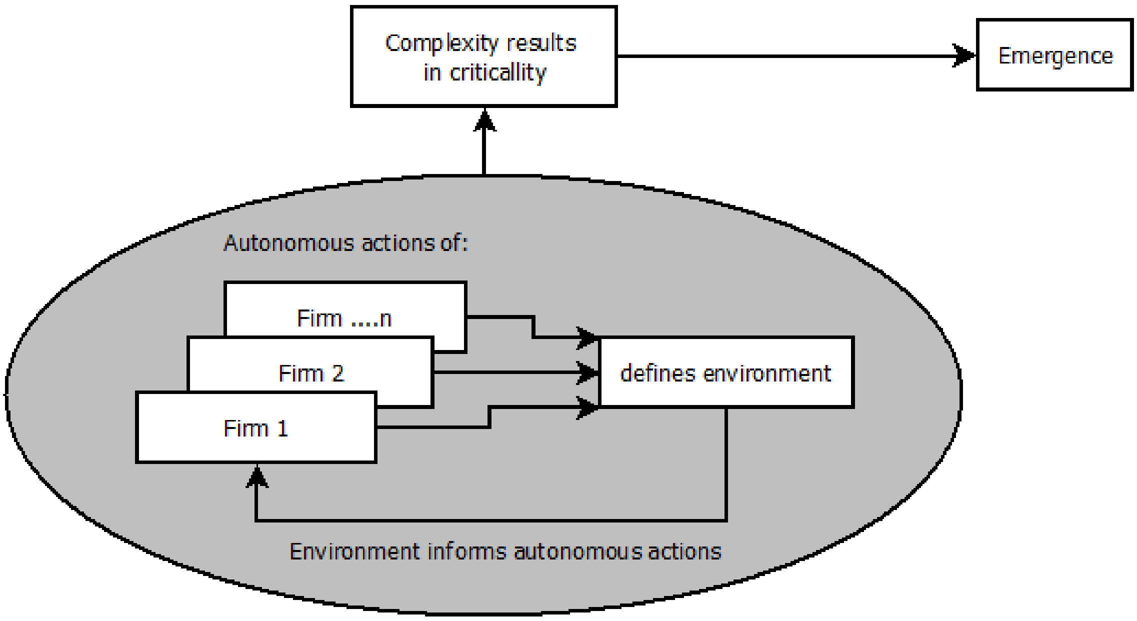


Figure 2—4: The processes of self-organisation and co-evolution

Source:

Supply networks can therefore be defined as a complex web of inter-firm relationships, the nature of which is to minimise costs through tight coupling. These are the very conditions that NAT associates with a system's vulnerability to catastrophe.

2.3 Summary and theoretical framework

The previous sections in this chapter show that there is an extant body of literature that frames supply networks as a CAS. The inherent complexity of a CAS is one of two cornerstones in normal accident theory, the other being the degree to which the supply network may be coupled.

The main contributions considered in this chapter are summarised in Table 2-4: Summary of constructs and concepts

Table 2-4: Summary of constructs and concepts

Construct	Concept	Contribution	Contributors
Complexity	Normal accident theory	Negative events occur as a consequence of complexity and coupling	(Norrman and Jansson, 2004; Perrow, 1999; Skilton and Robinson, 2009;

			Yang and Yang, 2010a)
	Criticality	Self-organisation – systems organise to a state whereby the re-organisation can be described by a thick tailed distribution of events	(Bak, 1999; Barabasi and Bonabeau, 2003)
		Punctuated equilibrium - periods of stasis followed by periods of change	(Bak, 1999; Brown and Eisenhardt, 1997)
	Far from equilibrium	Complex systems tend to organised states – not states of maximum entropy	(Prigogine, 1997)
Coupling	Normal accident theory	Coupling combines with complexity to create an environment susceptible to disturbances becoming coincident	(Norrman and Jansson, 2004; Perrow, 1999; Skilton and Robinson, 2009; Yang and Yang, 2010a)
Adaptation	High reliability organisations	Anticipation of possible disturbances results in organisational responsiveness to disruptions	(Leveson et al., 2009; Rijpma, 1997; Weick and Sutcliffe, 2007; Shrivastava et al., 2009a)

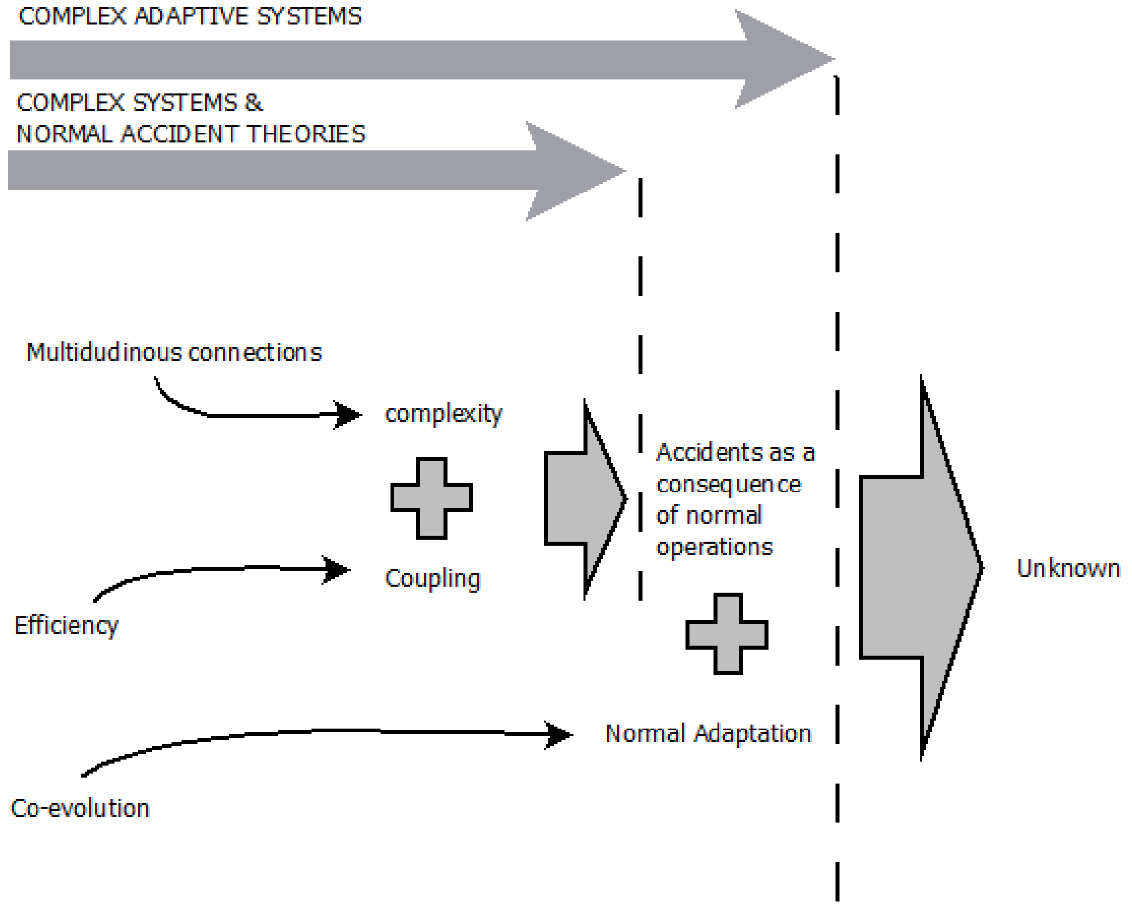
Normal accident theory in its existing form relies heavily on evidence drawn from technical logical systems that incorporate some form of human interaction. However supply networks have been shown to be complex systems with emergent properties that due to economic imperatives are inevitably tightly coupled. In this sense supply networks fit normal accident theory models. However there is a paucity of published material that incorporates adaptation in normal accident theory.

By incorporating adaptation as a variable within the framework of normal accident theory this thesis as its first contribution seeks to make clear the relationship between levels of disruption experienced by supply networks and the levels of adaptive capability of the network constituent's.

The literature describing supply networks as CAS generally supports the NAT perspective and argues that the complexity of supply networks combines with the supply chain management objectives of minimal inventory to develop a tightly coupled CAS. This leads to the formulation of the following research question:

Do supply networks comprising multiple connected supply chains experience periods of disruption as a consequence of normal operations?

Figure X summarises the theoretical framework developed in this chapter and which will provide the lens through which the phenomena of supply network disruptions will be examined.



Whilst this chapter has built a theoretical framework for the conceptualisation of adaptive agents in supply networks using a synthesis of NAT, CAS, and HRO theories to build a skeleton of normal operations and behaviour. However this framework falls short of specifying how such a network can be operationalized. The next chapter will address directly the theory pertaining to the operationalization of supply networks in the context of complex adaptive systems with the purpose of providing the foundation for the specification of theoretically underpinned operationalisable conceptualisation of the supply chain.

3 Operationalising Supply Networks

The previous chapter established the theoretical underpinning of supply networks, thereby providing the lens through which to view supply networks, and in particular, this thesis's phenomenon of interest: disruptions caused by disturbances generated by normal operations.

This chapter will build on the previous chapter to examine the literature relevant to the operationalisation of supply networks with the purpose of conceptualising the factors relevant to, and the process of, organising buyer-supplier relationships.

This chapter is organised as follows:

1. Market Organisation – theory relating to the organisation of economic activity which provides the contextual foundation for a firm's buying behaviours (transaction cost economics, TCE)

2. Supply strategy – structural and relational organisation of buyer seller relationships within the market context present in the literature describing market organisation (TCE and social exchange theory, SET)

3. Supplier selection criterion – how buying firms articulate their supply strategy through the specification of selection criteria and the operation of supplier selection processes.

4. Normal operations and normal adaptation – how buyer supplier relationships are managed in terms of transactions, relationship management and supplier switching decisions

The output of this chapter will be the theoretical anchor used in this thesis for operationalising and conceptualising supply networks.

3.1 Market Organisation

There are two dominant perspectives on the economic organisation of industrial activity: classical economics and neoclassical economics.

Classical economics is underpinned by a number of assumptions regarding the activity of a firm. The first of these relates to perfect knowledge and the ability of an organisation to make completely rational choices (Skinner, 1979). The second assumption relates to the mechanisms by which supply and demand are co-ordinated: classical economics assumes that this is achieved through the price mechanism and through price adjustments a Pareto efficiency of production is established.

Neoclassical economics challenges the assumption of perfect knowledge and posits that firms make imperfect decisions based on incomplete knowledge and imperfect processing of information (Marshall , 1930). This conceptualisation of bounded rationality infers that some organisations will have a greater capability to process more information more meaningfully, yielding a position of advantage in the pursuit of self-interest (Williamson, 1992; Simon, 1991; Williamson, 1996). The pursuit of self-interest is an important consideration in neoclassical economics as it requires organisations to consider the propensity of organisations with which they trade to behave opportunistically (otherwise known as moral hazard), and where appropriate, to mitigate against such behaviour through structural arrangements and contractual safeguards.

The neoclassical perspective has assumed dominance in the supply chain literature because it embraces the practical limitations experienced at the micro level of interactions between firms whilst not discounting the role of the price mechanism in buyer supplier arrangements. This thesis, in keeping with the vast majority of supply chain literature, will adopt the neoclassical perspective and the following sections will consider its theoretical foundation, robustness, and alternative/complementary theories.

3.1.1 Transaction Costs and Market Organisation

Williamson (1992; 1996; 1993a; 1993b) defines transaction costs as the costs incurred by a buying organisation to safeguard against moral hazard. These mitigation costs have been generally categorised into three themes: search, governance, and policing. Williamson’s original logic that these costs are a function of asset specificity and uncertainty, has been generally supported by empirical studies (Emery and Marques, 2011; David and Han, 2004; Maia et al., 2010; Shervani et al., 2007; Ke and Wei, 2007).

Williamson uses asset specificity as a measure of how easy or not it is to transfer transaction specific investments to other alternative transactions. High specificity denotes assets that cannot easily be deployed in alternative arrangements, thereby suggesting that their ownership is of strategic significance. Alternatively, low specificity describes assets that can easily be redeployed and therefore assume a low strategic significance. For the purposes of clarity assets are generally considered to refer to investments and assume a general description which includes human and physical assets.

Williamson's consideration of uncertainty generally refers to environmental uncertainty, the constituents of which have been distilled to market conditions, technology and behaviours. If any of these uncertainty dimensions are sufficiently dynamic such to defy prediction buying, then organisations mitigate by imposing contracts which are designed (often imperfectly) to dampen volatility.

The conceptualisation of transaction costs as a function of asset specificity and uncertainty allows researchers to use transaction costs as a predictor of inter-firm organisation. A situation where the buyer's and supplier's understanding of the transaction is complete describes a context of low moral hazard in which rationality dominates. In such a context uncertainty and transaction specific investments are negligible, and as a consequence, transaction costs are minimal as there is no required safeguard against moral hazard. This is what has been described as the perfect market.

Coase's (1990; 1937) conceptualisation of bounded rationality suggests that perfect markets rarely exist, and empirical work (e.g. (Ghoshal and Moran, 1995)) tends to a view that industrial transactional environments nearly always include degrees of uncertainty and transaction specific investments.

If either transaction asset specificity or transaction uncertainty is/are sufficiently high to ensure that a buying organisation cannot secure adequate protection against moral hazard at an economically viable cost, the resolution of how to organise economic activity is drawn towards the vertical integration of the transaction into the buying organisation. In such circumstances transaction costs have been minimised by eliminating or at worst internalising the moral hazard and Williamson described this form of economic organisation as hierarchical (Williamson, 1992).

However, many industrial supply relationships involve degrees of asset specificity and uncertainty that can be reasonably mitigated through economically viable organisation/safeguarding, such as contracting or shared investments. The resultant relationship between the buying and selling organisations is a hybrid of Williamson's market and hierarchical forms retaining the trade between legal separate identities but incorporating inter-firm structures supported by some form of governance. This organisational form is fundamental to the supply chain concept and the bedrock upon which much of the supply chain management theory has been developed (Emery and Marques, 2011; Ke and Wei, 2007; Kevin Burgess et al., 2006; Wever et al., 2012; Williamson, 2008). Figure 3—1 summarises the transaction cost framework described above.

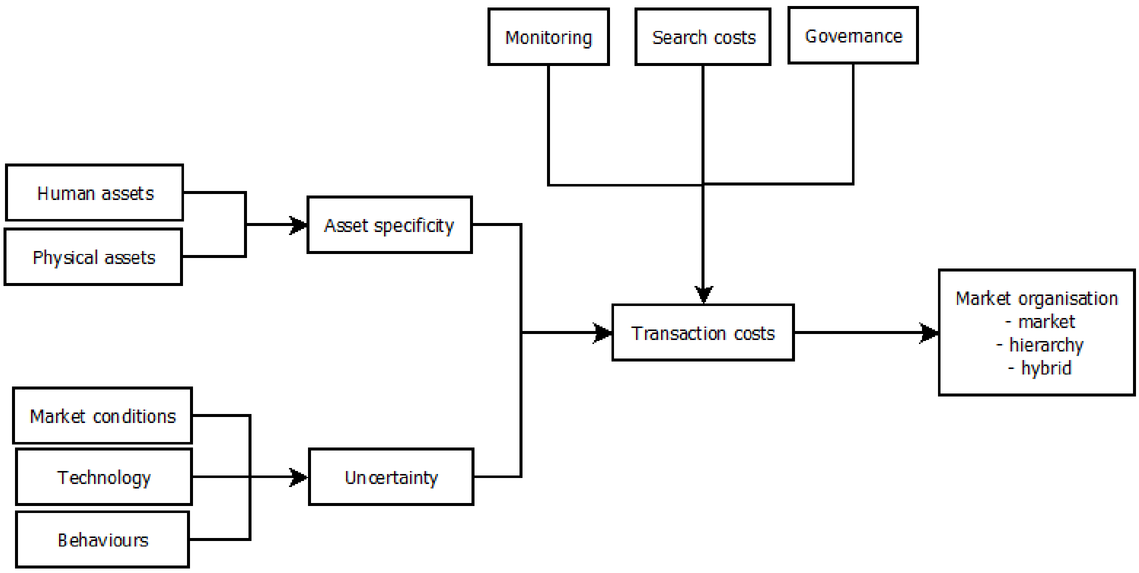


Figure 3—1: The transaction cost framework

The next section considers in more detail the form of opportunistic behaviour in order that mitigation strategies can be contextualised.

3.1.2 Transaction Cost Econommics and Opportunism

Williamson's original definition of opportunism as 'self-interest seeking with guile' does not meet with complete agreement, as Williamson himself accepts:

> Although there is growing agreement that bounded rationality is the appropriate cognitive assumption for describing economic organisation, there is less agreement on how the self-interestedness of economic actors should be described. Transaction cost economics has proposed that economic agents be described as opportunistic where this contemplates self-interest seeking with guile. That has turned out to be a controversial formulation. (Williamson, 1993b)

More recently, opportunism has been rephrased to reflect the propensity of organisations to act in their own self-interest (Williamson, 1993b; Ke and Wei, 2007; Free, 2008; Bunduchi, 2008; Nooteboom, 1996; Ireland and Webb, 2007; Joshi and Stump, 1999b), a behaviour that was originally conceptualised by Adam Smith (Skinner, 1979):

> *"By preferring the support of domestic to that of foreign industry, [he] intends only his own security; and by directing that industry in such a manner as its produce may be of the greatest value, he intends only his own gain."*

The crucial difference between these two definitions is that in the one case deceptive intent (i.e. violation of agreement) is implied, yet in the other, legitimacy can be found in classical economic reasoning which posits that the price mechanism is essential to establish equilibrium between supply and demand, as summarised by Marshall (1930).

Marshall's conceptualisation of supply, demand and the role of the price mechanism is captured by the classic supply curve formulation which is summarised in Figure 3—2.

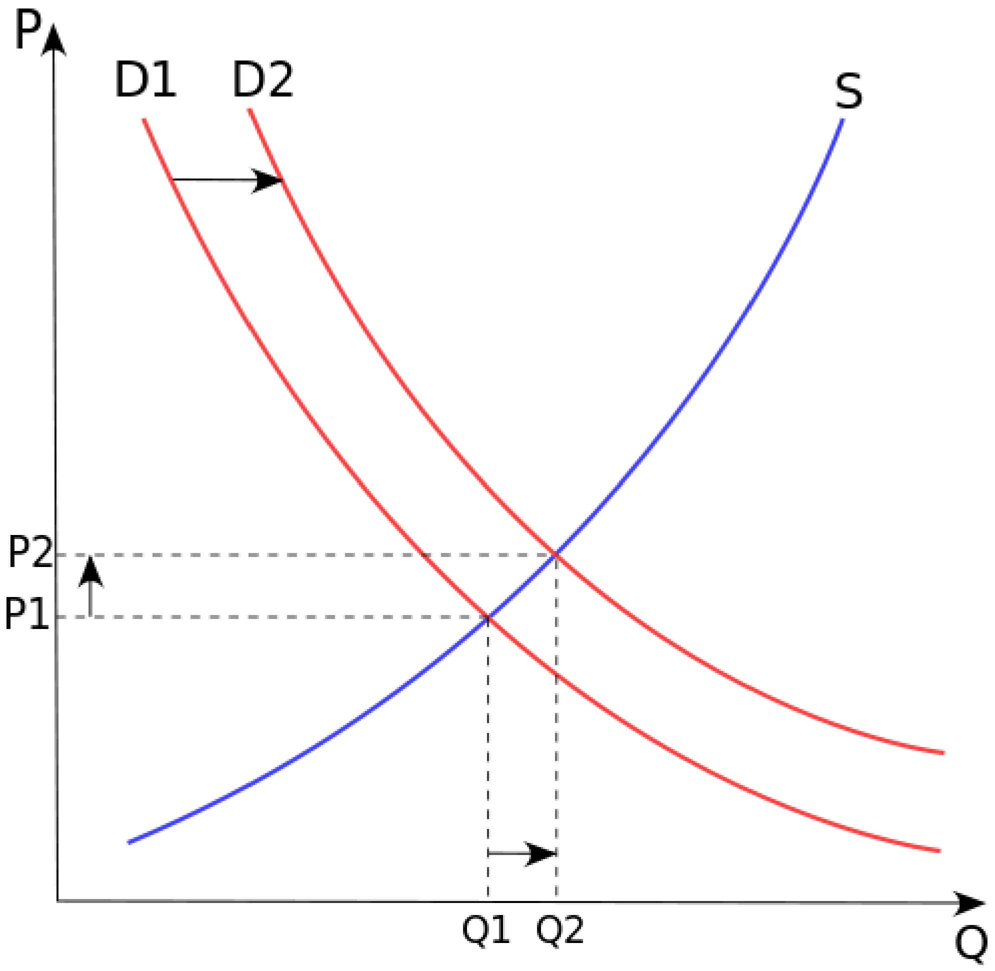


Figure 3—2: Marshall's classic supply and demand curve
The price P of a product is determined by a balance between production at each price (supply S) and the desires of those with purchasing power at each price (demand D). The diagram shows a positive shift in demand from D_1 to D_2, resulting in an increase in price (P) and quantity sold (Q) of the product.

Source: (Marshall , 1930)

Within this model increases in demand will result in increased prices. In a sense what Marshall proposes is that firms will always act in their own self-interest, for instance by increasing prices based on a perceived increase in demand that challenges the existing supply. The revised definition of opportunism therefore finds some support in classical economics; however, the price mechanism is not the only manifestation of opportunism.

Wathne and Heide (2000) provide evidence that opportunism persists in various forms, such as exaggeration, violation and misrepresentation, all of which are designed to increase revenue for the opportunistic firm at the expense of the exchange partner. Wathne and Heide (2000) use this evidence to locate opportunistic behaviour along two categorical dimensions: behaviour (passive or active) and circumstance (existing or new). The resultant forms of opportunism are described as evasion, refusal to adapt, violation and forced renegotiation, and are summarised in Figure 3—3.

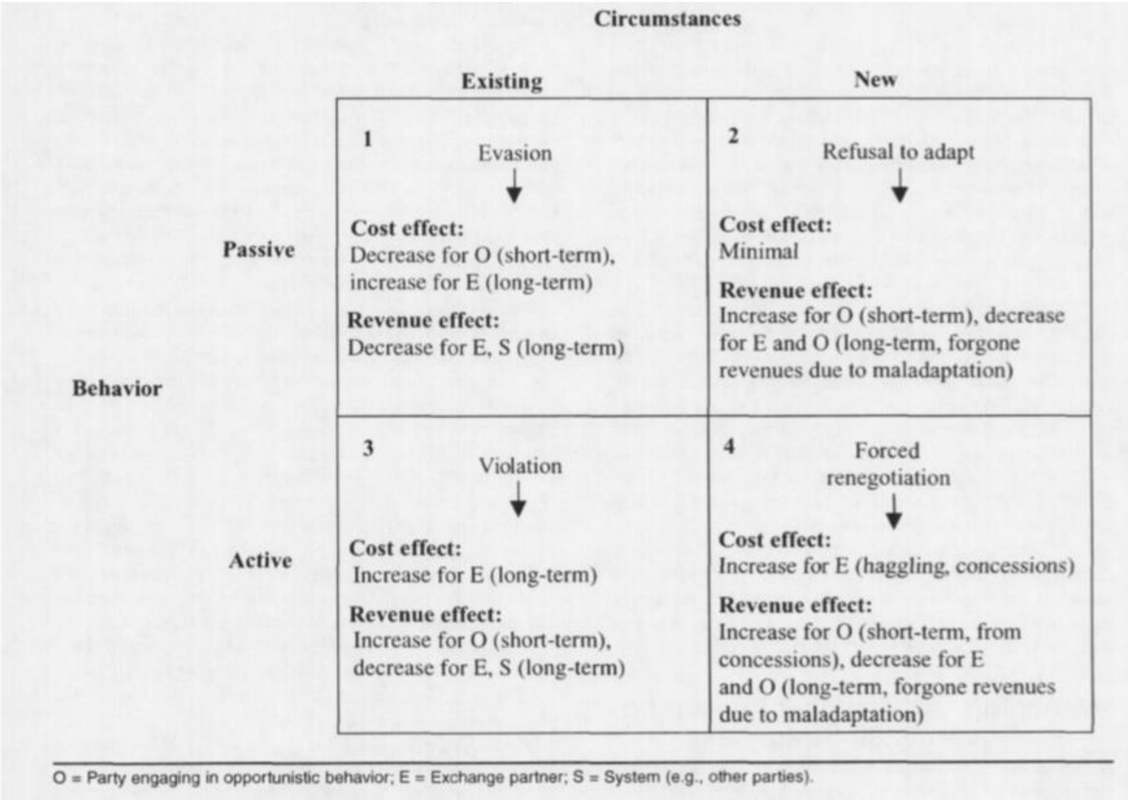


Figure 3—3: Forms of opportunism and possible outcomes

Source: (Wathne and Heide, 2000)

Examination of this model identifies the critical role of cost and revenue in defining opportunism and highlights its non-strategic nature through its prediction of long-term negative relational effects. In other words, opportunism does not entertain any long term considerations, or at least not within the relationship in which it is exercised. This description of opportunism is congruent with that of Porter's (1980) competitive strategy model, which positions the power of either a buyer or supplier as one of two dimensions that define the competitive context of a firm. Porter suggests that it is the objective of the firm to exploit any favourable position of power in order to create an advantage and to continually seek positions that offer such opportunities (see also (Dickson, 1966).

The crucial point is that just as firms are fundamentally motivated to act with self-interest, bounded knowledge ensures the decisions supporting self-interest are not always perfect. Wathne and Heide's (2000) passive behaviour represents legitimate (but not necessarily intended to be so) actions within an agreed framework, which may be formed just as easily from misunderstandings as they could be from design. This contrasts with active behaviours which conform to Williamson's original definition of opportunism.

Whilst Williamson's original conceptualisation of opportunism may not be widely accepted, the concepts of bounded rationality and motivations of self-interest have secured widespread acceptance in the literature and are now commonly accepted to refer to opportunism. This allows the formulation of economic organisation which is summarised in Figure 3—4.

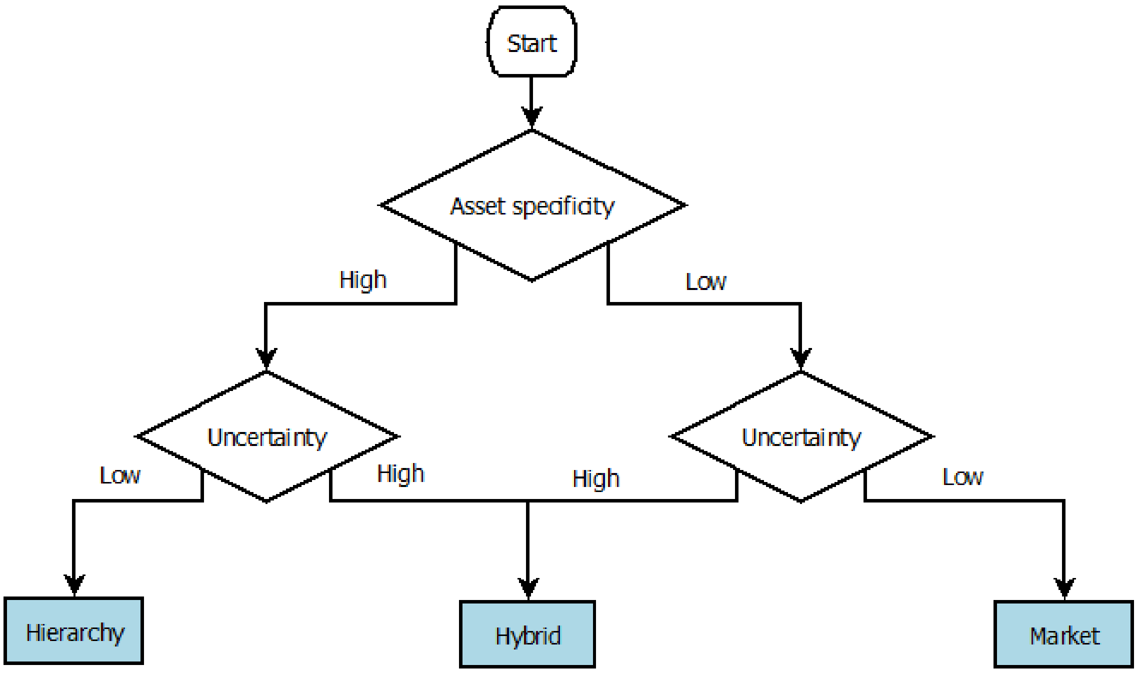


Figure 3—4: Economic organisation

Regardless of intent, firms must act to protect themselves from the consequences of self-interest, whether executed legitimately or with guile. The design of mitigation draws the discussion to a consideration of the antecedents to opportunism, which within the literature have generally been framed as: dependence, formalisation, relational norms and uncertainty (e.g. (Hawkins et al., 2008).

Dependence reveals asymmetric transaction benefits and lends power to either a buyer or supplier depending on who has the greatest dependency on the other (Ireland and Webb, 2007; Macneil, 1980). In situations where the supplier has less dependency on the relationship with the buyer than the buyer has on the supplier, then the supplier is considered to have more power and is more likely to participate in hostage taking strategies, such as threatening to form new relationships or prioritising more important relationships.

In the hybrid form of economic organisation, activity asset specificity and in particular asset specific investments have been identified as a measure of relational power and dependence (Wathne and Heide, 2000; Achrol and Gundlach, 1999; Joshi and Stump, 1999a; Provan and Skinner, 1989). Asymmetric investment in transaction assets results in asymmetric dependency and provides a context within which the least dependent partner is more likely to act opportunistically by adopting a strategy of hostage taking framed as a threat to exit the relationship or to continue to participate in it under conditions of extended privilege (Gundlach et al., 1995). However, it would be wrong to consider dependency in isolation, as it is conditioned by social norms which Joshi (1997a) found to be the deciding factor in whether or not firms behave opportunistically.

Heide (1992, p.34) described relational norms as expectations about behaviour that are shared by a group of decision-makers and that have been shown to govern individual exchange relationships between firms. These norms incorporate many factors including mutual benefit and trust, conflict resolution, and flexibility (Gundlach et al., 1995).

Others have found that relational norms in and of themselves have little influence over opportunistic behaviour. Instead they found relational exchanges (within which norms are embedded) to be a more effective mitigation of the propensity for firms to act opportunistically. Relational exchanges place value in non-economic exchange rules, for instance the exchange of trust for cooperation whereby a buyer may trust a seller based on previous experience and in return a seller will cooperate with a buyer based on mutual trust.

To a large extent relational norms and relational exchanges represent means by which the impact of uncertainty is dampened, as due to the exchange participating organisations are assured that in the event of uncertainty the relational development of trust secures degrees of flexibility and cooperation. However, in the absence of relational norms and exchanges uncertain outcomes generate a landscape within which possibilities for opportunistic behaviour thrive. It is not surprising therefore, that in the absence of relational norms uncertainty is generally found to positively relate to the propensity for firms to act opportunistically.

Uncertainty therefore creates contexts whereby actors are more likely to behave opportunistically. This has been shown to be particularly true of what has been termed environmental uncertainty, which includes performance uncertainty. Performance uncertainty isn't necessarily constrained to focal relationships as it can reflect the broader context of performance, such as those located in the network. Performance uncertainty refers to whether or not a buyer or seller can be relied upon to meet their transactional obligations. If contractual performance is unsated then the context presents an opportunity for renegotiation favouring the most powerful actor (Joshi and Arnold, 1997b; Sako and Helper, 1998; Schilling and Steensma, 2002).

The relationship between formalisation and opportunism is probably more surprising as it has been shown that the greater the level of formalisation, which includes contracts (Cavusgil et al., 2004; Dahlstrom et al., 2000; Deeds and Hill, 1999), the greater the propensity for firms to behave opportunistically (Provan and Skinner, 1989; Dahlstrom and Boyle, 1994; Gilliland and Manning, 2002; George, 1984) by violating or renegotiating the contract in keeping with Wathne and Heide's (2000) active opportunism. This contrasts with research findings into the relationships between social norms and opportunism, which generally support the argument that nurtured social norms found in trusting committed relationships mitigate opportunism (Hunt and Morgan, 1994; Morgan and Hunt, 1994)

The influence of uncertainty, relational norms, and dependency on opportunism can of course be framed as common sense. However, the findings relating to the role of formalisation as an antecedent of opportunism are somewhat counterintuitive and potentially polarised.

A number of researchers have found that formalisation relates positively with opportunism, and this sits in stark contrast with the position taken by neoclassical economists who propose formalisation as a means of contracting to protect organisations against the dangers of moral hazard (Joshi and Arnold, 1997b; Sako and Helper, 1998; Schilling and Steensma, 2002).

Some explanation for why contracts can summon opportunistic behaviours is found in the detailed process of contracting, which involves collapsing the future into the present. MacNeil (1980) highlights the difficulty of this process in terms of how a contract can release unilateral power to both participants: sellers through a contract can enforce buyers' commitment to buy goods, and similarly buyers can enforce sellers' commitment to supply. When this phenomenon is combined with bounded rationality, formalising creates an environment within which both buyers and sellers can act opportunistically in the enforcement and interpretation of incomplete definitions of the transaction (e.g. (George, 1984).

Further insights into the tensions between the economic perspective and the social perspective regarding formalisation can be developed through the consideration of the different types of opportunism specified by Wathne and Heide (2000). Active opportunism represents some form of redefining previously defined boundaries of behaviour embedded in, or imposed upon, the transaction between a buyer and seller. Properly designed formal contracts can undoubtedly and logically do, provide some protection against opportunistic actions, and as Williamson himself accepts, opportunistic behaviour of this nature is not necessarily common or widespread. In contrast to active opportunism, passive opportunism is primarily concerned with the actions of self-interest constrained by the contract (typically incomplete due to bounded rationality) framing a transaction. The arguments supporting the positive relationship between formalisation and opportunistic behaviour are evidenced by actions that Wathne and Heide (2000) would categorise as passive, in other words they do not breach the formal contracting however they test the intent of the contract to its limit. Parkhe (1993) identifies a potential pitfall for formal contracting which may go some way to explaining why relational contracting has attracted so much attention within the supply chain literature:

> *"Faced with high costs of court adjudication, firms are reluctant to resort to courts or other third-party policing mechanisms and rely instead on private ordering."* (Parkhe, 1993)

It therefore follows that a combination of formal contracting and informal contracting is likely to produce better levels of relationship performance than either achieves in isolation. Moreover, formal contracting sets out boundaries within which informal or social contracting can be applied in order to avoid passive opportunism.

This thesis will take as its focus normal operations and therefore exclude active opportunism in the form of violation or renegotiation of contract frameworks. However, it will accept opportunistic behaviour within the terms of a contract that has already been agreed. That is to say, if a contract fixes the price for a short period of time then a supplier will conform to this requirement for the duration of the contract. When the contract expires, then the supplier is at liberty to modify the price at which they sell their product regardless of what effect this would have on the buyer. With this in mind the following section considers in more detail informal contracting, its application to mitigating passive opportunism, and its implications on inertia.

3.1.3 Social Exchange Theory (SET)

SET accounts for valued exchanges between organisations other than economic. The key difference between transaction economics and social exchange is that social exchange anticipates a relationship which persists in time, which results in social exchanges having value in driving future behaviours of partners ((Dwyer et al., 1987, p.13).

Morgan and Hunt (1994) proposed a model whereby trust and commitment are deemed to be the currency of social exchange between trading organisations (Figure 3—5).

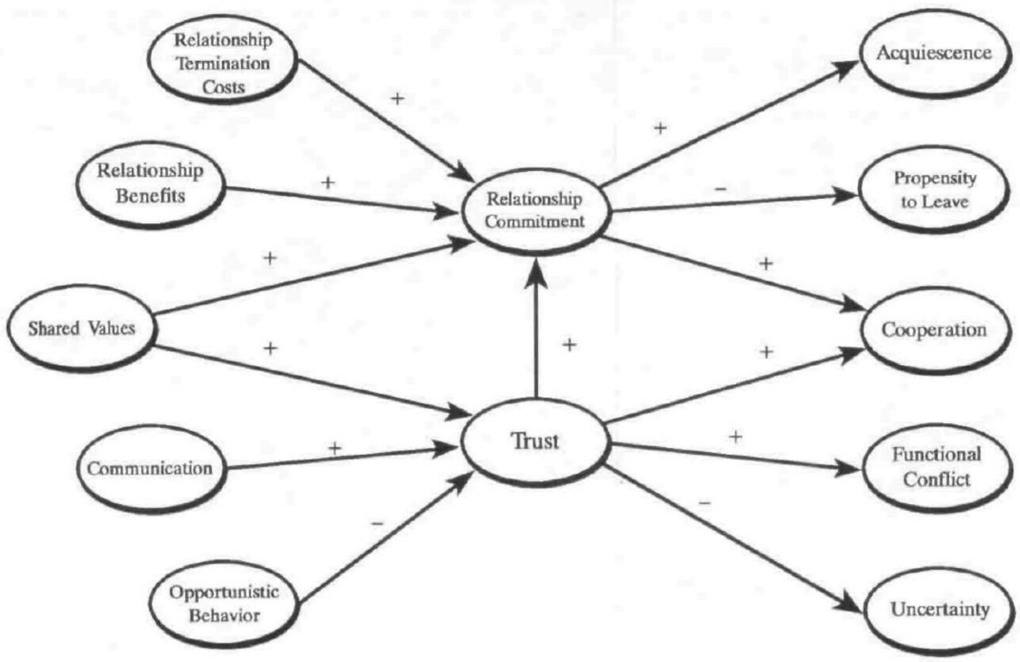


Figure 3—5: Trust and commitment as the currency of social exchange between trading organisations

Source: Morgan and Hunt (1994)

SET defines relational commitment as the belief that the continuation of a relationship is of paramount importance (Morgan and Hunt, 1994; Ko et al., 2001) Given this definition it is not hard to agree with the logical argument presented by Morgan and Hunt that trust is an antecedent of relationship commitment. Again there is general acceptance that the definition of trust is centred on a firm's confidence that its trading partner is reliable and possesses high levels of integrity (Morgan and Hunt, 1994; Ko et al., 2001).

The value of this currency is found in the consequences of organisations developing trust and commitment, these are: partner acquiescence, reduced propensity to leave the relationship, increased cooperation, increased functional conflict, and decreased uncertainty, and are summarised in Table 3-1.

Table 3-1: The consequences of trust and commitment

Outcome	Source	Benefit
Acquiescence and propensity to leave	(Kumar et al., 1992)	Provides stability but reduces transaction costs
Cooperation	(Achrol and Stern, 1988; Anderson and Narus, 1990, p.45)	Coordination and shared goals – shared self interest
Functional Conflict	(Dwyer et al., 1987)	Creative challenge improves performance
Decision Uncertainty	(Achrol and Stern, 1988)	Decreases because decisions are shaped by mutual interests and shared understanding

Analysis of these outcomes suggest that they all serve some purpose in developing shared objectives and therefore secure stability through aligned self-interest. If self-interest is aligned then dyads become coordinated resulting in hybrid forms of organization with governance

The goal of the firm must therefore be to seek circumstances that foster trust and commitment described by the antecedents to trust found in Morgan and 'Hunt's model

Termination costs are the costs incurred by an organisation when it exits a relationship. By inference these may include searching for a new trading partner, and the transfer of relational assets from the terminated relationship to some new relationship or ultimately liquidation. Termination costs therefore represent a factor in the consideration of alternative trading arrangements, not unlike the consideration given to asset specificity in TCE: the higher the termination costs of the existing relationship to lower the propensity of the organisation to exit. In short, high termination costs introduce a greater commitment to the existing relationship.

In a similar vein, relationship benefits whilst also an antecedent to trust and commitment are a key consideration of self-interest. Firms are obliged to monitor alternative relationships and to constantly appraise the relative attractiveness of engaging new partners compared to existing relationships. If relational benefits in alternative arrangements are greater than those in the existing relationship, motivations of self-interest will direct a focal organisation towards (after careful consideration of termination costs) exiting the current arrangements to establish more beneficial alternatives. TCE requires acts of self-interest of this form to be mitigated through formal contracting, whereas SET suggests that by ensuring that the relational benefits outweigh alternatives, existing relationships can be made enduring.

The motivation for organisations to seek partnerships with similar like-minded organisations is in part anchored in the belief that shared values decrease the propensity of partnering firms to act opportunistically. The evidence which provides weight to this assumption is found within the literature relating to the way in which firms identify themselves and internalise identification in the form of culture. Morgan and Hunt (1994) found empirical support of shared values and a positive relationship with both commitment and trust, and this is therefore a very important factor in the development of ensuring inter-firm relationships.

Firms that share information do so to deliver relational benefits, and in consequence subtly increase termination costs whilst at the same time reinforcing any shared values through reciprocal arrangements. Communication therefore develops trust, and trust as already established, increases relational commitment.

Widespread support for the Morgan and Hunt model of trust and commitment can be found in the literature relating to supply chain management (Chen et al., 2011; Chen et al., 2007; Madlberger, 2009), strategic alliances, and most significantly in the literature that links TCE and SET in a unifying framework for the mitigation of moral hazard.

The central tenant in supply chain management is the coordination of activity related to the flow of materials, cash and information across organisational boundaries. Given this it is not surprising to find that TCE and SET are often quoted as being the theoretical foundations for theories for the development of supply chain management constructs. In particular, the supply chain literature focuses on the role of inter-firm relationships in developing a clean demand signal across multiple organisational boundaries. This can only be achieved through communication designed to deliver relational benefits in the form of reduced inventory and supply chain responsiveness. In engendering communication as a beneficial relational attribute, organisations anticipate an enduring relationship that requires specific investments, thereby increasing termination costs. In anticipation of beneficial relationships buying organisations seek to identify suppliers with durable attractiveness (i.e. those that share similar values). Furthermore, the negative impacts of opportunism are avoided through the development of shared goals.

It is not surprising, therefore, to find that information sharing and consequential collaboration are key components in the development of aligned processes (Wilding and Humphries, 2006; Monczka et al., 1998; Chen et al., 2011; Madlberger, 2009; Kwon and Suh, 2005; Nyaga et al., 2010). As such it should be possible to map supply chain literature against TCE and SET basic principles.

There are a number of supply chain frameworks that have been broadly synthesised by Cooper and Lambert (2000). Table 3-2 summarises the supply chain literature and its alignment to the SET conceptualisation of trust and commitment.

Table 3-2: Supply chain literature and its alignment to SET

Supply chain processes (Lambert and Cooper, 2000)	**SET Construct**	**Description**
Customer relationship management	Communication - trust - uncertainty	Information sharing to smooth demand and reduce uncertainty
	Communication – trust/commitment - cooperation	
Customer service Management	Communication - trust - uncertainty	Product/service knowledge enables uncertainty to be reduced
Demand Management	Communication - trust - uncertainty	Understanding customer demand patterns and variation enables better planning
	Communication – trust/commitment - cooperation	
Order fulfilment	Communication – trust/commitment - cooperation	Coordination of distribution activities
Manufacturing Flow Management	Communication – trust/commitment - cooperation	Forecasting and the organisation of batches
Procurement & purchasing	Communication/shared values – trust/commitment – cooperation/functional conflict/uncertainty/propensity to leave/acquiescence	Supplier relationships configured cognisant of context – commitment reduces uncertainty
Product development	Communication/relationship benefits/shared values – trust/commitment – cooperation/acquiescence	Products developed collaboratively - reduces uncertainty and risk, increases mutual benefits

By considering supply chain management as operationalising TCE and SET, the literature exposes a factor not directly addressed in either theory, although it is implicit in both – power. Although power (alternatively expressed as a function of dependency) is considered as an antecedent of opportunism, its beneficial role in coercion as a means of developing commitment and collaboration is neglected.

Power is a function of dependency (Macneil, 1980; Stump and Joshi, 1998), which in turn is a proxy for relational benefits. It also allows the more powerful partner to impose information sharing processes on its less powerful partner, lends leverage to the powerful partner, and imposes termination costs on the less powerful partner, thus it can be seen that power is a mechanism by which the antecedents of trust and commitment can be generated.

However it is worth noting that a balance must be struck between power and trust as it can be perceived as opportunist if the benefits of a relationship are disproportionately allocated to the powerful partner. A summary of the literature on power is provided in Table 3-3.

Table 3-3: Literature on the different aspects of power

Power Aspect	Source
Evolution of power through increased dependency	(Amaral and Tsay, 2009)
Different perceptions (buyer vs supplier) of the role of power	(Ambrose et al., 2010)
Inadequate trust – use power to develop commitment	(Co and Barro, 2009)
Power as a key determinant of relationship configuration	(Cox, 2004)
Location of inventory – distribution of benefits	(Emery and Marques, 2011)
Impact of power in developing consolidation in supply chain – powerful actors dictate	(Hingley, 2001; Hingley et al., 2011)
Strategies for balancing trust and power: identifying authority, common identity, using boundary spanning ties, and justice	(Ireland and Webb, 2007)

3.1.4 Synthesis of Social Exchange Theory and Transaction Cost Economics

Both TCE and SET share a common consideration of opportunism (Bunduchi, 2008).. On the one hand TCE relies on opportunism to define make or buy decisions and the subsequent organisation of economic activity (Williamson, 1992; Williamson, 1993b) whilst on the other, SET embeds opportunism as one of a number of factors that determine beneficial non-economic aspects of a relationship (Morgan and Hunt, 1994). Integral to both theoretical frameworks is the notion that opportunism is best mitigated through either explicit or implicit contracting.

TCE takes the position that opportunism is mitigated through appropriate organisation of economic activity, and where necessary (in hybrid forms) the use of explicit contracting

Explicit contracts take the form of detailed specification of the transaction in terms of price, quantity, payment terms, penalties and incentives (Achrol and Gundlach, 1999; Cavusgil et al., 2004), and the contract is drafted in consideration of specific scenarios which are considered potential hazards (Dahlstrom et al., 2000). Explicit contracts make clear the apportionment of risk and penalties according to a bilateral agreement. Within the context of opportunism, explicit contracts can reduce uncertainty by specifying the governance rules relating to the relationship, although inevitably such arrangements also increase dependency between the two parties as a consequence of the penalties and incentives embedded in the agreement.

SET argues that opportunism is negatively related to trust, inferring that trust mitigates opportunism. Morgan and Hunt (1994) identify positive relationships between shared beliefs/norms and information sharing, inferring that these two relational attributes can be used to develop trust and therefore mitigate opportunism.

Implicit contracts are designed to address unanticipated contingencies, which may be the result of bounded rationality or asymmetrical information. In an uncertain world some researchers have argued that explicit contracts are rarely used in practice, with relationship participants instead preferring to stabilise the relationship through commitment reinforced by cooperation, collaboration, and joint problem solving framed by implicit contracts.

The extension of both implicit and explicit contracts is that both stabilize relationships by increasing dependency through increased costs of departing the relationship (Morgan and Hunt, 1994). Furthermore implicit contracting according to Morgan and Hunt (1994), delivers strategic benefits in excess of those found in explicit contracting, such as joint problem solving, functional conflict, and cooperation in contexts which cannot be anticipated. The SET approach to mitigating opportunism has also been framed as a virtuous circle, with the consequences of trust and commitment in the form of cooperation deepening the levels of trust between the relationship partners (Morgan and Hunt, 1994).

Transaction cost economics’ concentration on economic aspects of the relationship puts aside social relationships which have benefits such as cooperation and mitigation of opportunistic behaviour and problem joint problem solving, and this limits the explaining power of TCE (Ghoshal and Moran, 1995). In the same vein, SET underemphasises the fundamental economic basis for business to business relationships. It is therefore not that surprising to find a number of papers (Heide and John, 1992; Bunduchi; Heide and John, 1990; Heide and John, 1988; Jones et al., 1997) that have described the integration of SET and TCE into a single unifying framework as the best approach to increasing explaining power.

Nooteboom (1996) parameterises opportunism and then seeks to address each parameter directly through the development of a number of strategies that are contingent on a firm’s context within a network. Within Nooteboom’s (1996) framework firms can either tighten or loosen their relationships using either adversarial or cooperative strategies to manipulate the parameters of: switching costs, value of supplier/buyer to focal firm; incentives for opportunism, opportunity for opportunistic behaviour, behavioural propensity for opportunism and impact. Nooteboom’s ({2604 Nooteboom 1996/a;}} typology of strategy is summarised in Figure 3—6.

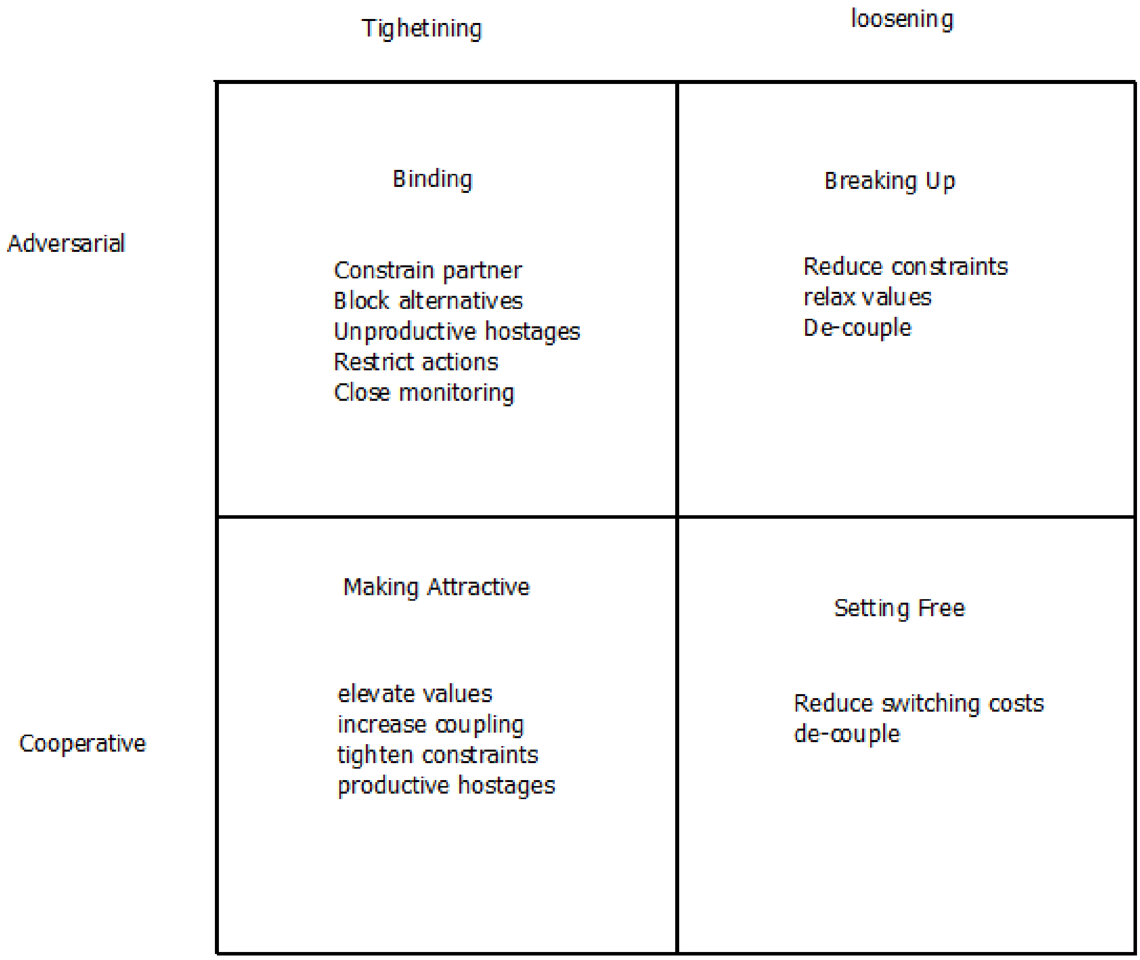


Figure 3—6: Integrated framework for typology of strategy

Source: Nooteboom (1996)

The essence of Nooteboom's (1996) research is that relationship governance should be designed cognisant of the objectives and context of the relationship. Others (see Table 3-4 for summary) have sought to expose the interaction between explicit and implicit contracting, suggesting that the level of formal contracting impacts social exchange and vice versa.

Table 3-4: Interactions between explicit and implicit contracting

Contribution	Source
Trust, power and transaction costs. Power related to dependencies	(Bunduchi, 2008)
Trust and commitment result in transaction specific investment	(Payan and Svensson, 2007)
Opportunism included in SET as behavioural variable. TCE is very narrow and opportunism not ubiquitous	(Ghoshal and Moran, 1995; Toumanoff, 1984)
TCE and the organization of economic activity frames social exchange	(Heide and John, 1990)
Network structure drives asset specificity, uncertainty and frequency of interactions. Social networks define the drivers of TCE. Networks define hybrid forms of organization	(Jones et al., 1997; Landa and Wang, 2001)
Types of exchange governance drive SET mediating variables of trust and commitment	(Kee-hung Lai, 2009; Lamothe and Lamothe, 2012)
Trust drives perceptions of behavioural uncertainty which drives explicit contracting forms	(Vandaele et al., 2007; Wei et al., 2012)
Strategic flexibility delivered by trust driving balanced investment in transaction specific assets. Flexibility best secured through trust	(Young-Ybarra and Wiersema, 1999)

Both TCE and SET describe mechanisms by which relationships in hybrid forms of market organisation can be tuned according to the levels of risk and uncertainty perceived by a firm. Furthermore, both theoretical approaches use dependency (trust and commitment or formal penalties and incentives) as the main instrument of governance.

Figure 3—7 synthesises the various integrated frameworks for TCE and SET.

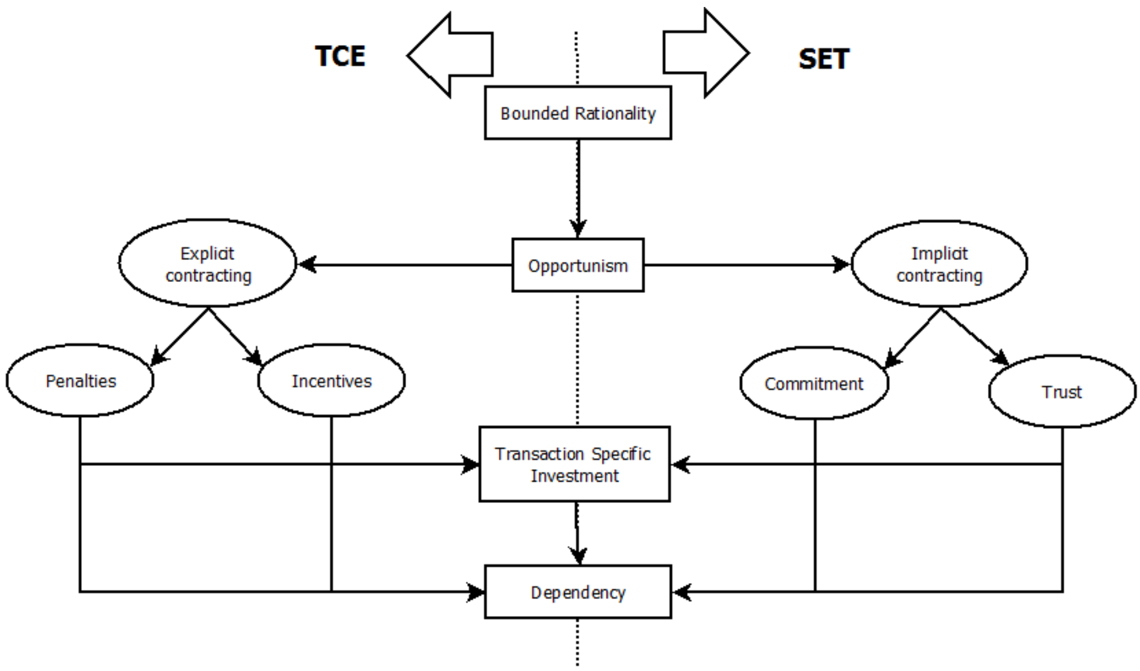


Figure 3—7: Integrated frameworks for TCE and SET

The consequence of regulating a relationship using either social exchange value or a system of penalties and incentives inevitably leads to the development of relational inertia, which is a vital component in any CAS. Without friction Bak's (1999) sand pile would not be critically organised and without inertia it can be argued that supply networks, while complicated, may not be complex (i.e. emergent and critically organised).

It has already been argued that complex tightly coupled networks may constitute a system vulnerable to inevitable disruptions, but the role of adaptation and in particular collaboration as a means by which disruption risk can be mitigated, are unexplored in a network context. This results in the following research question:

> *What is the impact of adaptation and collaboration between supply chain participants on the level of disruption experienced by the network?*

The next section will consider the literature describing relational inertia and in particular its role in supplier switching decisions.

3.1.5 Supplier Switching

The theories underpinning relationship formation (TCE and SET) accept that firms have bounded knowledge and adapt with the purpose of pursuing objectives of self-interest. As has been argued previously, these basic foundations for firm interactions create an environment that is perpetually changing; a context that constantly tests the basis on which a firm's current relationships were formed inevitably surfaces occasions where the buyer or seller decides that an existing relationship can be bettered by alternative arrangements.

The literature has established that there are three factors that drive the consideration of whether or not to change suppliers (Thomas Pfeiffer, 2010; Wagner and Friedl, 2007) 1) the cost of switching, 2) the cost of finding a new supplier, and 3) value of the existing relationship. The cost of switching incorporates the costs of disengaging with the existing supplier and the cost of creating a new relationship. Disengaging costs may include: contractual penalty clauses, dismantling relationships, and dismantling or withdrawing from transaction specific investments. Search costs are the costs associated in finding and qualifying alternative suppliers, and these vary depending on how scarce the type of supplier resource is within the broader network. Perhaps harder to quantify is the embedded value in the existing relationship, which according to SET would include levels of cooperation, functional conflict, and reduced uncertainty (Morgan and Hunt, 1994).

Wilson (2012) argues that a consideration of only switching costs is too simplistic and should be combined with a consideration of search costs as both can influence the supplier switching decision independently. Search costs are highest when there are few suppliers, although it can be logically argued that *in extremis* the monopoly of supply can only be achieved if the supplier is easily found. In the contrasting situation of plentiful supply, search costs are maintained at a low level because an alternative supply is plentiful. Equally scarce supply drives relational investment which increases switching costs.

Geiger et al. (2012) argue that the social exchange value created through trust and commitment is the dominant supplier switching consideration. Strategic relationships are founded on an anticipation of future transactions which enables the development of trust and commitment, thereby releasing relational value in the form of cooperation and problem solving. The strategic content of relational value makes it difficult to quantify: strategy anticipates continued relationships and to some degree sacrifices immediate benefits from alternative arrangements in an expectation of future benefits developed by effective competitive barriers yielding preferred relational status. It is therefore not surprising to find that firms prioritise relational value over more easily quantified economic benefits, as relational value is more likely to be the key that unlocks future markets and ensures a firm's survival/prosperity.

Geiger et al.'s (2012) analysis drew on a definition of commitment that could be unpacked into two forms: calculated and affective commitment. The former is a need related to high levels of dependency, whilst the latter is a desire. An examination of Morgan and Hunt's (1994)model aligns calculative commitment to the benefits and costs of a relationsh, whilst affective commitment is aligned to shared beliefs and communication. Irrespective of the commitment form, Geyskens et al. (1996) found a strong correlation between commitment (affective and calculative) and interdependency. This was later broadly confirmed by De Ruyter et al. (2001) who anchored the correlation in relation specific investments, and replacibility which others have argued is part of a dependency construct (Leger et al., 2006; Kumar and vanDissel, 1996; Petersen et al., 2008), alternatively expressed as a moral hazard (Williamson, 1993a; Riordan and Williamson, 1985).

Dependency is therefore a fundamental driver of switching costs and relational value; in addition, dependency also drives inertia which conditions rational switching decisions formed from economic (as opposed to economic and relational) considerations.

Figure 3—8 summarises the literature describing the process of supplier switching and how this is conditioned by commitment developed inertia.

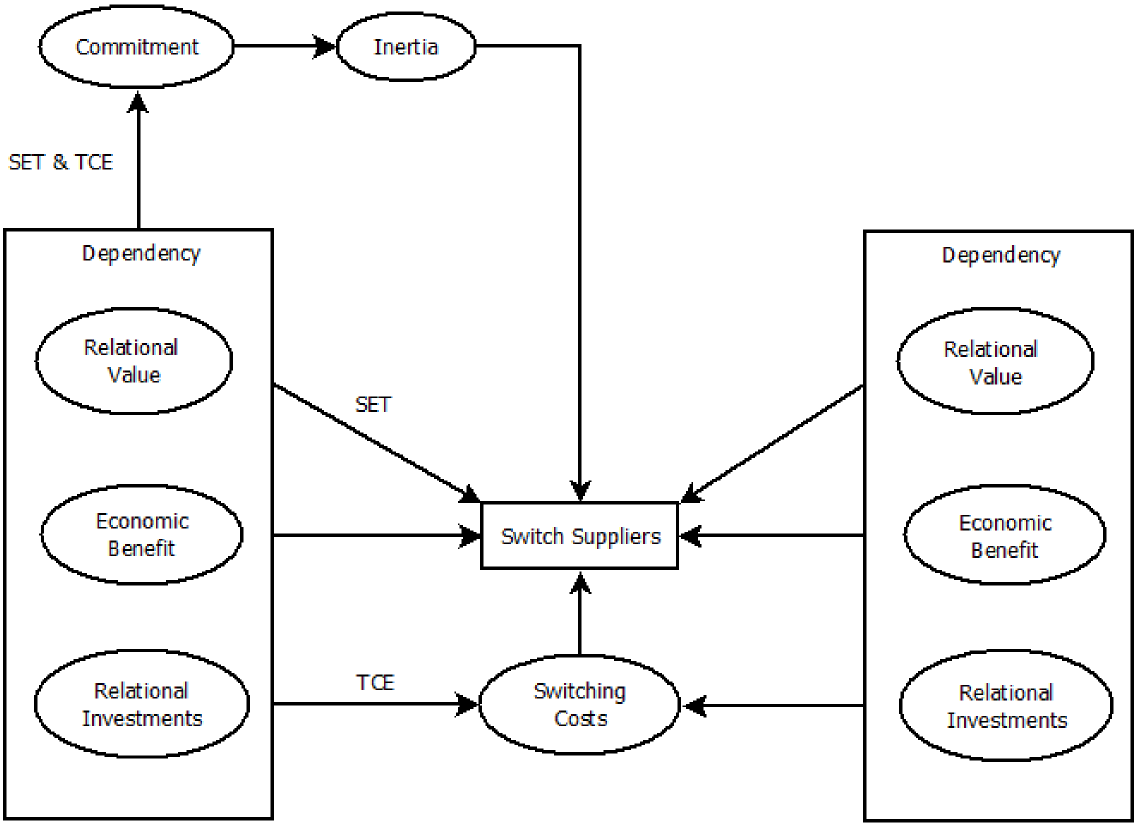


Figure 3—8: Supplier switching conditioned by commitment developed inertia

3.2 Supplier Strategy and Supplier Selection Criteria - Why Form Relationships?

Skinner (1979) is really the original architect of the supply chain for it was he who pointed out the benefits of specialisation and the division of labour in terms of increased efficiency. This Smithsonian view of economics inevitably results in the economic system self-organising into pockets of specialised production (or value adding processes), which become connected by the conversion processes necessary to produce a specific product.

Inevitably, pockets of specialisation evolve into organisational forms that can now be recognised as firms; legally separate entities that provide a differentiated specialisation to other organisations, which operate under conditions of bounded rationality (Coase, 1937).

In all contexts apart from a monopolistic supply and vertical integrated firms, a buying firm will be required to make a rational selection of supplier based upon a process of differentiation. The resultant process is an amalgamation of strategy formed from: 1) the buying firm’s context; and 2) the differentiation of suppliers shaped by supplier attributes and the buying firm’s priorities.

This section will therefore consider how extant knowledge informs the development of supply strategy before considering more detailed supplier selection criteria as a means of differentiating suppliers and establishing supplier preferences.

3.2.1 Supply Strategy

In the early 1980s in keeping with the new conversations developing around the supply chain (Houlihan, 1985). Kraljic (1983) recognised that:

> *“In many companies, purchasing, perhaps more than any other business function, is wedded to routine. Ignoring or accepting countless economic and political disruptions to their supply of materials, companies continue to negotiate annually with their established networks of suppliers or sources. But many purchasing managers' skills and outlooks were formed 20 years ago in an era of relative stability, and they haven't changed. Now, however, no company can allow purchasing to lag behind other departments in acknowledging and adjusting to worldwide environmental and economic changes. Such an attitude is not only obsolete but also costly.”*

In an effort to remedy this situation Kraljic (1983) synthesised supply risk with item criticality to develop a matrix of contextually contingent supply strategies, which could be used to guide buying firms to leverage context to their advantage.

Kraljic (1983) describes the process of developing a supply or purchasing strategy as a four stage process. The first phase is to classify supply in terms of item criticality and supply risk, the second phase is to assess a firm’s buying power relative to potential suppliers, the third phase is to develop a purchasing strategy based on the first two phases, and the final phase is the development of an action plan to develop more favourable supply options.

The purpose of classification within the Kraljic's portfolio approach is to establish a context of supply which drives the tasks, information and decision process required to support the purchasing process. These classifications can be presented in a Boston Matrix as summarised in Figure 3—9.

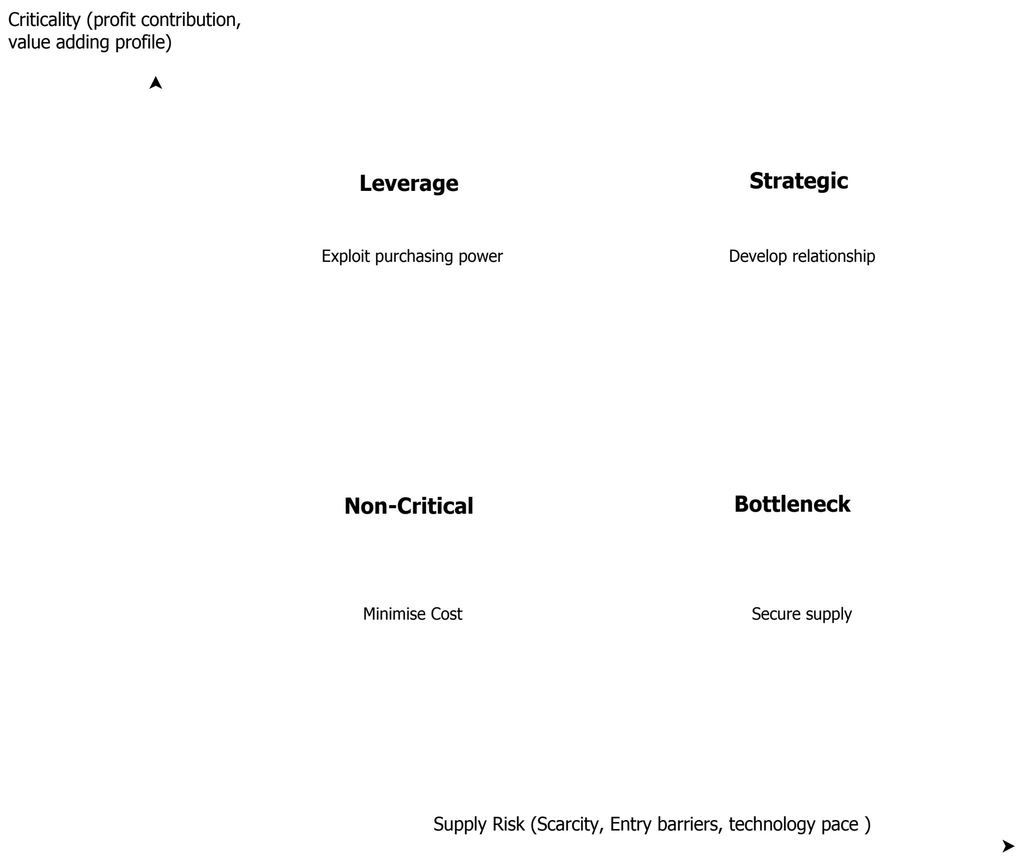


Figure 3—9: Product purchasing classification matrix

Source: Kraljic (1983)

The second phase of the Kraljic (1983) approach is concerned with dimensionalising the assessment of supplier and buyer power. Kraljic provides ten dimensions for assessing suppliers (Kraljic, 1983), which can be generalised according to Table 3-5:

Table 3-5: Dimensions for assessing suppliers

Ident	Supplier Strength determined by:	Buyer Strength determined by:
1	Market size vs. supplier capacity	Purchasing volume vs. main supply capacity
2	Market growth vs. capacity growth	Demand growth vs. capacity growth of supplier
3	Capacity utilisation or bottleneck	Capacity utilisation of main units
4	Competitiveness	Market share compared to main competition
5	Return on investments and return on capital	Profitability of products
6	Cost and price structure	Cost and price structure
7	Break even stability	Cost of non-delivery
8	Product uniqueness	In house production capability
9	Barriers to entry	Entry costs for new supply
10	Logistics situation	Logistics

This framework provides the means by which a buyer's context, as defined in phase 1, can be used to build an understanding of the attractiveness of potential suppliers. The object of the exercise is to where possible minimise supplier power whilst maximising buyer power. This process in and of itself does not provide the buyer with the means by which to allocate importance weights to particular dimensions, but is useful in providing a framework which can subsequently be used to determine the relative buyer and supplier power across each dimension based on the specifics of a buyers context.

The third phase is concerned with assessing the buying firm's vulnerability to supply through a combination of the context shaped by phase 1, and the supplier assessment dimensions of phase 2. Essentially, this uses the relative strengths of buyers and suppliers to define three broadly defined strategic directions: exploit, balance, and diversify.

If buyer power exceeds supplier power in any dimension, the buying organisation is directed towards a strategy of exploiting that power in relation to that dimension. If buyer and supplier power are matched then a balanced strategy is recommended, and if supplier power exceeds the buyer's power then Kraljic (1983) suggests that the buyer should adopt a strategy of supply diversification.

The final phase provides more detail to the strategy formulation outlined in the preceding phase by guiding the design of an action plan to improve a buyer's position by considering the nine dimensions summarised in Table 3-6.

Table 3-6: Aspects to be considered when designing an action plan to improve a buyer's position

Policy	Buyer power greatest	Supplier power greatest
Volume	Spread	Centralise
Price	Spot Buy	Contractual protection
New suppliers	Maintain contact	Search
Inventories	Low	High
Own production	Reduce capability	Build capability
Substitution	Maintain contact with alternatives	Search for alternatives
Value engineering	Force suppliers to provide value	Initiate in house
Logistics	Minimise cost	Secure supply

The portfolio approach advocated by Kraljic (1983) has assumed a number of subtle variations (e.g. (Harrison and van Hoek, 2011; Chopra and Meindl, 2010) reflected in a number of different dimensions, including power (Campbell and Cunningham, 1983) and relationship specific investments (Bensaou, 1999).

The dimensional of power assumes particular significance in the consideration of how many suppliers should be engaged, something Kraljic (1983) chooses not to address directly, instead providing general guidance in terms of 'secure supply'. The inference being that in situations where dependency is high (supply risk is also high) then a supply of materials is best secured through adopting multiple sourcing strategies. Further support for this approach can be found in the competitive strategy of Porter (1980) who suggested that the greatest cost advantage can be secured by ensuring competition amongst suppliers.

Alternative perspectives regarding the best way to secure supply have been proposed by Deming (1986) who suggested that the greatest security of supply at the lowest cost is best achieved through higher levels of collaboration with selected suppliers.

Although Kraljic (1983) provides guidance regarding the supply strategy to be adopted with selected suppliers, it falls short of guiding the practitioner with regard to the number of suppliers that should be engaged. Broader strategic considerations present somewhat of a paradox in this respect. Deming (1986) suggests that optimal costs are achieved through superior quality achieved by adopting a single supplier. However, Porter (1980) favours the use of competition to check any advantage a supplier might seek to develop. Porter's perspective finds broader support from Kraljic and others, who perceive the most advantageous posture for minimal cost and security of supply is found in what TCE refers to as the perfect market (plentiful supply and low switching costs).

Dimensions such as power add more detail to any strategic analysis but are essentially a re-phrasing of scarcity of supply, likewise, supplier power is conceptually anchored in supply scarcity, and relational power is reflected in relation specific investment. It is therefore not surprising that the portfolio form has persisted and is now accepted as the principal approach to purchasing strategy (e.g. (Cox, 2004; Wagner and Johnson, 2004))

Despite its dominance the portfolio approach to developing strategy is not without its critics who have challenged its applicability based on: its appropriateness to the development of sustainable competitive advantage; the restriction of two dimensions on which the strategy is formulated (Dubois and Pedersen, 2002) and its static formulation (Cox, 2004; Dubois and Pedersen, 2002). Furthermore, although the portfolio approach provides a useful framework the dimensions of criticality and supply risk have proved hard to operationalise. Boundaries between high and low criticality/supply risk need contextualising and indexing (Harrison and van Hoek, 2011).

Although the portfolio approach is focused on the dyad as the defining element of buyer seller relationships it accepts that the relationship must exist in a context of other relationships which can be generalised in an assessment of supply and demand scarcity. An alternative approach to the dyadic unit of analysis is to be found by using the network as the unit of analysis. This approach does not make assumptions about context, rather it explicitly accounts for all relationships between the firms that can be found in a network of connected dyads (Dubois and Pedersen, 2002).

The essence of the network approach is twofold: 1) that the potential for optimising a system is greater than the potential for optimising a dyad (Axelsson and Easton, 1992); and 2) the system changes requiring the embedded firms to react to a new re-defined environment (Blankenburg and Johanson, 1992). Whilst this approach is theoretically sound it puts aside the constraints of bounded rationality which infers the autonomous actions of any firm are imperfect, thereby initiating a perpetual cycle of adaptation as firms react to the parallel imperfect action of other firms. This is of course a perfect description of a CAS as described in Chapter 2.

The consideration of bounded rationality is a useful guide to the integration of portfolio approaches into the more holistic network approach of strategy development. The portfolio approach recommended by Kraljic (1983) and others has proved popular because it can be operationalised heuristically, and may represent the best approach given the constraint of bounded rationality. However, even Kraljic recognised the ultimate framework for developing supply strategy must accept the dynamism of context, requiring any analysis to be perpetually revised:

> *"The stable way of business life many corporate purchasing departments enjoy has been increasingly imperilled. Threats of resource depletion and raw materials scarcity, political turbulence and government intervention in supply markets, intensified competition, and accelerating technological change have ended the days of no surprises. As dozens of companies have already learned, supply and demand patterns can be upset virtually overnight".* (Kraljic, 1983, p.109)

The actions of individual firms in the formulation of supply strategy are therefore inevitably anchored in an analysis that assumes a dyadic context but accepts that a network context can only ever be partially known to the focal firm. When actions constrained in this way are located in a network of parallel actions based on analysis made in conditions of bounded rationality, the perpetual adjustments to the actions of others is captured by the network unit of analysis and forms a description of a CAS.

Portfolio approaches structure the decisions made by the elemental components of a supply network and represent one rule amongst several that combine to define the dynamic nature of the environment or network.

The need to include multiple dimensions in the formulation of supply strategy has led to the dominance of the portfolio approach as a framework within which products can be classified and placed in the context of buyer and supplier power. This guides the development of a supply strategy and the on-going strategy of positioning the organisation for improved returns.

Although Kraljic's (1983) selected analytical dimensions of criticality and supply risk have been challenged, they persist because they can be used to reflect many of the alternative, more specific, dimensions in supply risk formulations. Furthermore, the perpetual review of supply risk, and for that matter criticality, means that the matrix can be applied in a dynamic context yielding an applicability that is constrained only by the widely accepted phenomenon of bounded rationality and the less well understood consequences of parallel autonomous actions.

However, the development of strategy, whilst yielding strategic direction, does not address the full range of supplier criteria, or how these criteria are used in differentiating potential suppliers from each other with the intent of securing the best possible economic outcome for buying organisations. This process undoubtedly contributes to the characterisation of supply as plentiful or scarce, and allows the construction of the following research question:

> *What is the impact of market structure on the level of disruption experienced by networks?*

The next section will address the literature relating to supplier selection criteria and how these criteria are operationalised in the supplier selection process.

3.2.2 Supplier Selection Criteria

The previous section defined how context is the key determinant of supply strategy, which is essentially the contextual leveraging or mitigation of buyer or supplier power by a buying organisation. This section will present and analyse the literature relating to the differentiation of alternative suppliers and the selection process

Distillation of Kraljic's (1983) ten dimensions of supplier selection criteria defines four themes: 1) the ability of a supplier to be flexible (dimensions 1,2, and 3 in Table 3-5), and in particular their ability to flex capacity; 2) the financial stability of a supplier (dimensions 5 and 7); 3) cost (dimensions 4 and 6) and 4) delivery (dimension 10).

Scarcity of supply (dimensions 8 and 9) is more of a consideration in the formulation of the relationship than a basis of selection/differentiation.

All of Kralijic's four thematic supplier selection criteria align well with four of the five dimensions determined from the empirical survey work of Dempsey (1978), Dickson (1966) and Weber et al. (1991): 1) ability to flex capacity; 2) cost; 3) vendor stability (competitiveness, and financial stability measures) and 4) price/cost. Furthermore, Kraljic's dimension of competitiveness can be positioned as a reasonable proxy for the combined effect of all four, but essentially are also inclusive of quality, a dimension identified by others (Weber et al., 1991; Dempsey, 1978; Dickson, 1966) as a fifth generalised dimension of supplier selection criteria. Whether or not it is accepted that Kraljic's themed supplier selection criteria align completely with the empirical findings of Weber and others, it is certainly true that Kraljics theory finds broad support in empirical research (Gelderman and van Weele, 2005)

Kraljic's (1983) argues that product uniqueness is created by material scarcity/technology/and barriers to entry. Uniqueness limits a buyer's power and the likelihood that price can be negotiated down. The inclusion of this factor in Kraljic's model is interesting because most alternative or complementary models (Dempsey, 1978; Porter, 1980) Dickson (1966), Weber et al. (1991) and Dempsey (1978) situate power as exogenous to the buyer supplier relationship and contingent on the industry sector. The ultimate arbitrator of this dimension must be the empirical evidence of Dickson (1966), Weber et al. (1991) and Dempsey (1978), which does not identify power as a dimension used in the supplier selection process. However, this does not mean that buyer or seller power is irrelevant, as it undoubtedly plays an important part in developing a firm's perception of risk and propensity to act opportunistically.

Dempsey (1978) used a survey of 379 US firms to develop a five canon description of supplier selection criteria. This which was supported by Dickson (1966) who surveyed 273 purchasing managers and distilled a list 23 supplier selection criteria, which was in turn confirmed by Weber et al. (1991), who although adopting a similar approach focused their attention on just-in-time supply strategies. Table 3-7 represents a synthesis the three foundation articles and the 23 supplier selection criteria.

Table 3-7: Supplier selection criteria

Factor	Rank		
	Dickson	Weber	Dempsey
Quality	1	1	2
Delivery	2	2	1
Performance history	3		6
Warranties and claim policies	4		
Production facilities and capacity	5	5	7
Price	6	3	3
Technical capability	7	6	5
Financial position	8		11
Procedural compliance	9		13
Communication system	10		15
Reputation and position in industry	11		10
Desire for business	12		
Management and organisation	13	8	9 (control) 16
Operating controls	14	10	
Repair service	15	11	4
Attitude	16	7	12
Impression	17		
Packaging ability	18	9	17
Labour relations record	19		18 (moral and legal) 20
Geographical location	20	4	19
Amount of past business	21		
Training aids	22		14
Reciprocal arrangements	23		

Essentially there is broad acceptance of the criteria across the three surveys; however Dempsey (1978) used canonical analyses to reduce the number of factors to five canonical functions: vendor stability, basic economic criteria, geographic affinity, attendant services and assurance mechanisms. Demsey (1978) goes on to argue that the canonical functions can be organised into two groupings, with supplier differentiation achieved through a consideration of price, quality and delivery, and vendor qualification provided by performance and stability

Dempsey's (1978) canonical analysis provides the underlying structure to the broad categories used in the supplier selection process, although the exact formulation of the structure is accepted as being dependent on context. Table 3-8 summarises

Dempsey's five fundamental supplier evaluation criteria and their underpinning dimensions.

Table 3-8: The five fundamental supplier evaluation criteria

Variables	Factors				
	Financial Stability	Price	Delivery	Flexibility	Quality
Labour Relations	0.73				
Management & organisation	0.71				
Financial Stability	0.63				
Production Facilities	0.57	0.35			0.32
Moral/legal issues	0.55				
Price		0.72			
Quality		0.69			0.34
Delivery Capability		0.68			0.41
Geographic Location			0.67		
Attitude Toward Buyer			0.66		
Performance History			0.57		
Bidding Compliance			0.48		0.41
Packaging Capability			0.48		0.36
Training Aids				0.82	
Aid and Service				0.76	
Repair Service				0.67	0.4
Technical Capability	0.39			0.61	
Reputation	0.41		0.31	0.48	
Control systems	0.34				0.62
Progress communications	0.31		0.31		0.55

Source: Dempsey's (1978)

3.2.2.1 Factor Loading Matrix Vendor Attributes

Despite almost four decades of research into supplier selection criteria, Dempsey's list of five fundamentals and the list of 23 dimensions (Weber et al., 1991; Dickson, 1966) has remained relatively unchanged (Renforth and Chawla, 2012; Swift, 1995; Wilson, 1994). However, the variables and the importance weighting of each variable is understandably contextual as previously argued in this and previous chapters.

3.2.3 Drivers of Supplier Selection Criteria

The previous section highlighted and classified supplier selection criteria, with Dempsey (1978) providing a canonical framework of five supplier selection thematic criteria anchored in empirical research. This section addresses the literature regarding how the relative importance of the different criteria is influenced, and once again Kraljic (1983) provides a reasonable starting point for this discussion.

Kraljic (1983) located the drivers of supply strategy along two dimensions: 1) importance of the item in terms of value added, cost contribution and profit contribution; and 2) the risk of supply expressed in terms of supply scarcity, substitutability, the pace of technology, and entry barriers.

Most firms have sufficient data to operationalise the importance of an item to their business (Zolkiewski and Turnbull, 2002). They will for instance have more or less complete knowledge of the costs, and the profit contributions of an item, this in turn yields a reasonable understanding of value contribution. However, all the components of supply risk are by necessity exogenous to a buying firm, and are framed by bounded knowledge.

Despite Kraljic's (1983) framework being underpinned by a significant body of empirical literature (Bensaou, 1999; Gelderman and van Weele, 2005; Caniëls and Gelderman, 2005; Ellram et al., 2002)

(Bensaou, 1999; Gelderman and van Weele, 2005; Caniëls and Gelderman, 2005; Ellram et al., 2002)

a consensus of how to operationalise supply risk remains elusive. Notwithstanding the dominance of the dyadic perspective in much of the supply chain literature, there are some notable conceptual papers that direct the reader to considering sources of risk other than process. Peck (2005) for instance identifies four levels of risk: process, network, infrastructure and environment, which she describes as interrelated, perhaps hinting at why Kraljic's (1983) dimension of supply risk is so hard to operationalise. Pecks model is summarised in Figure 3—10:.

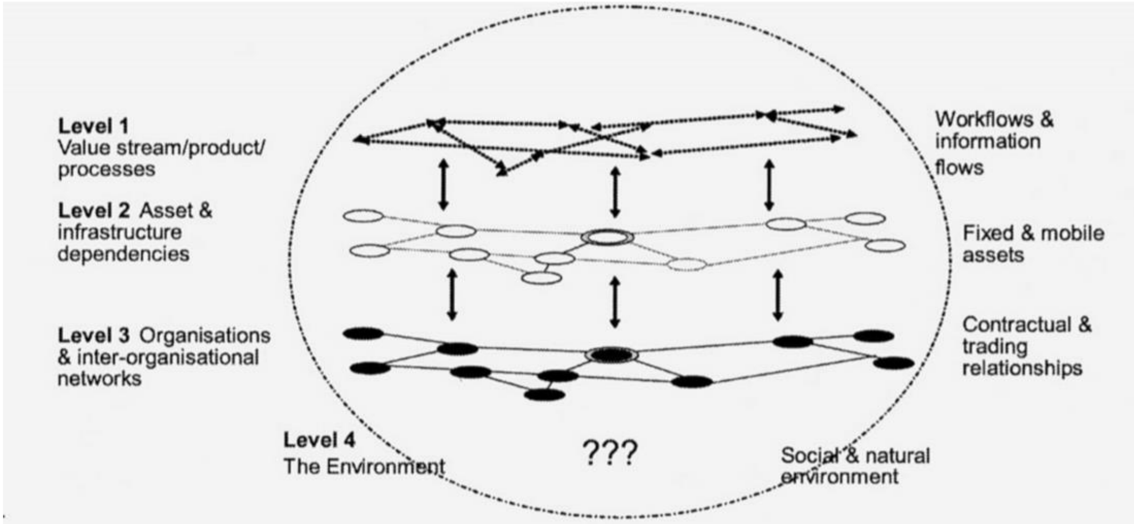


Figure 3—10: The four sources and levels of risk

Source: Peck (2005)

If a lens of 'normality' is applied to Peck's (2005) model we can argue for the special treatment of level 4: natural disasters, which are unexpected and largely unpredictable in their specificity (Sheffi, 2005). However, the other three levels of this model provide a useful framework through which to view Kraljic's (1983) dimension of supply risk.

The first level is process risk and is concerned with the flow of information and materials along the supply chain. Disturbance in material flow can be caused by disturbed information flow and demand/supply variation. The second level, much like the third level, is concerned with dependencies between firms and between firms and infrastructure elements. Infrastructure does not generally alter in its designed form over the short term; however, it is susceptible to disruption phenomenon akin to natural disasters, in other words difficult to predict and rare. This thesis is concerned with normal operations and will therefore put aside for the moment any specific consideration of infrastructure or environmental sources of risk.

3.2.3.1 Uncertainty

The body of literature describing supply chain risk management provides some guidance about how process risk can be identified and quantified. The underlying premise in this literature is that risk is the product of the probability of an event occurring and the negative consequences of that event.

In the main this literature maintains the dyadic unit of analysis and is generally concerned with the use of inventory buffers (see Waters (2003) for detailed formulation) to mitigate the risk of supply disturbances which have a probability of occurrence calculated from a firm's experience of supply and demand variation. The projection of variation in supply and demand as a source of risk (with determinate probabilities and impacts) has led some to suggest means by which the negative consequences of the risk mitigation (increased inventory buffers) could be mitigated; the most prevalent of which is the trading of information for inventory to minimise the so-called bullwhip effect identified by Forrester (1961). Trading real time demand information with suppliers inevitably attracts relationship specific investment, if only in the form of process and technology, with such investments increasing dependency and therefore increasing the supply risk associated with a restricted number of suppliers.

The bullwhip effect is a consequence of each tier in the supply chain bundling their orders for economic efficiency. This masks the real time demand signal and consequently generates demand uncertainty. The bullwhip effect is summarised in Figure 3—11.

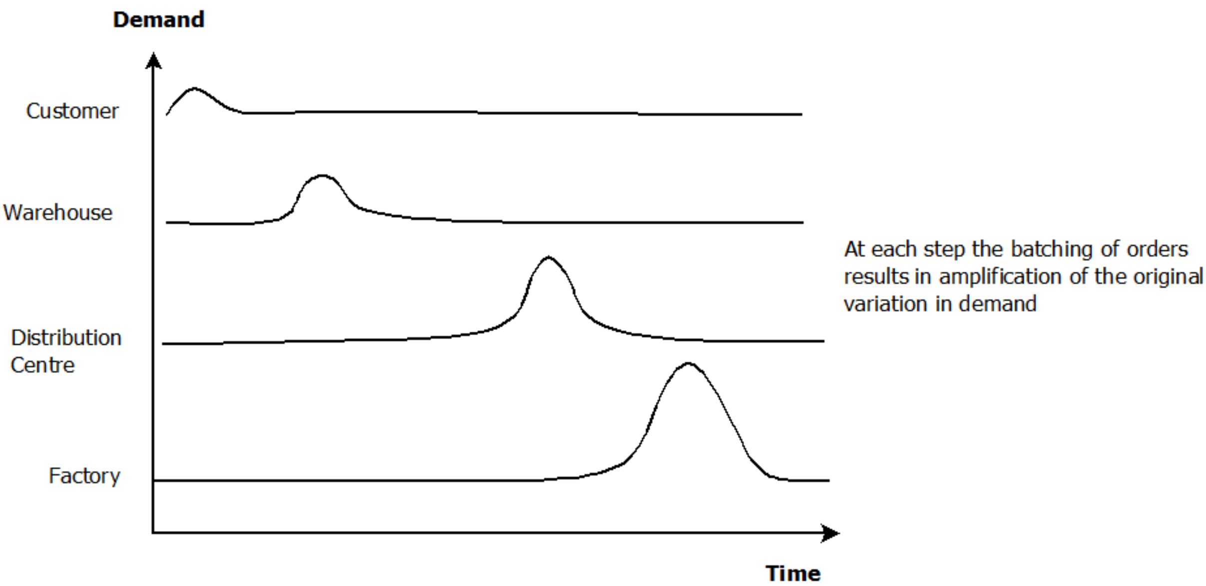


Figure 3—11: The bullwhip effect

There are sources of uncertainty other than supply/demand, such as quality and price/cost fluctuations. Variations in delivered quality require a buying organisation to first of all buffer against this uncertainty through a good inventory. Cost/price fluctuations create uncertainty, and in much the same way as other sources of uncertainty, drive buying organisations to forward buy and fix intake costs, in other words build inventory buffers.

The last source of uncertainty can be found in the actions of competitors (Akanle and Zhang, 2008; Allen et al., 1986; Anderson, 1999; Ashton, 2008) who must seek to create advantages by modifying the risk landscape in their own favour by participating in disruptive innovations and other competitive actions. These sources of uncertainty require a different form of mitigation: responsiveness as opposed to inertia inducing dependency strategies (Bergquist, 2006; de Leeuw and Fransoo, 2009; Kim et al., 2006; Miller and Friesen, 1980). Responsiveness may require a firm to use pricing as a means of tailoring demand to match capacity or it could involve reviewing the priorities assigned to supplier selection criteria and revising which suppliers get selected.

Uncertainty in its various forms is certainly a driver of supply risk. Given the preferred mitigation of efficiently (through the moderating effect of information sharing) building inventory buffers it is a little surprising to find no literature that describes the associated increase in supply risk generated by the increased dependency that results from information sharing processes/technology. The first driver of supply risk is therefore uncertainty.

3.2.3.2 Dependency

Dickson (1966) and later Caniels and Gelderman (2005) and, Zsidisin and Ellram (2003) suggest that buyer and seller dependency, and by association supply risk, can be used to define a firm’s behaviour in a particular context (as described by Kraljic’s (1983) matrix). However, this approach draws on a limited consideration of alternative supply, and is therefore still essentially a dyadic conceptualisation and does little to address sources of supply risk from the broader network perspective.

Chopra and Sodhi (2004b) also emphasise the ‘dependency on a single source of supply as well as the capacity and responsiveness of alternative suppliers’ as a driver of disruption risk. This aligns with their identification of ‘percentage of a key component or raw material procured from a single source’ as a driver of procurement risk. In both cases, Chopra and Sodhi (2004b) suggest these risks can be mitigated through the effective combination of redundant suppliers/capacity.

The perception that multiple sourcing is an effective means of securing supply was confirmed by a number of survey based research articles (Hult and Craighead, 2010; Zsidisin et al., 2008). By creating multiple supply pathways firms develop their potential to re-route material flows in the event of disturbances or disruptions (Bode et al., 2011; Bonabeau, 2007; Li et al., 2010; Surana et al., 2005; Greening and Rutherford, 2011; 2011a).

The principle of building alternative pathways is effectively ensuring that the network does not become over dependent on a few suppliers. The measurement of a system’s dependency on constituent elements is one that has been addressed by social and socio-economic network analysis and this provides some guidance as to how network dependency can be calculated. In effect, this approach calculates how dependent a network is on each participant in the network; if the spread of dependency is large then the inference is that the network is overly dependent on a small number of its constituents and supply risk is therefore greater compared to a scenario where the variation in dependency is small.

In broad terms, centrality is a synonym for dependency. Even within these formal descriptions of dependence expressed at a network level of analysis it is far from clear which centrality measure is the most appropriate. For instance, it is not necessarily clear whether degree centrality or betweeness centrality provides the best measure of dependency.

The simplest measure of centrality is degree centrality which measures the number of links a node (which represents a firm) has. By comparing the degree centrality of each node it is possible to establish conceptually the dependency of a network on each node. Furthermore, it is possible to extend this measurement by establishing the mean and the variation from the mean for the entire population of nodes and through this characterise the diversity of network’s centrality. This group measure describes the context of dependency variation.

Betweeness centrality, like degree centrality, can assume a unit identity or a group identity. In either case betweeness centrality measures the number of times a node is used to bridge to another node, and is often used as a description of power or influence.

Whilst this analytical approach is of undoubted utility in developing an understanding of supply risk, it has been criticised due its assumption that each firm has complete knowledge of the network (Varga et al., 2009; Allen et al., 1986; Baldwin et al., 2010). Nevertheless, this approach provides a useful structure for the operationalisation of supply risk and it can be used to conceptualise supply substitutability. Plentiful suppliers with a low variation in centrality across a network describes a market where switching is easy, and one in which there has not been any need to develop dependency as a means of mitigating moral hazard.

A network perspective also helps conceptualise barriers to entry. Network structures that persist describe an environment where buyers stick with suppliers, whilst structures that are highly dynamic reflect a willingness of buyers to try alternative suppliers. These two contrasting descriptions of network dynamics portray inertia as a proxy measure for a barrier to entry.

Inertia is also a reflection of dependency, with high dependency relationships having high inertia and low dependency relationships low inertia. By logical extension, dependency when assessed at a network level can describe not just the scarcity of supply but also the barriers to entry contained within a network, thereby providing the means by which supply risk can be operationalised.

3.2.4 Operationalising the Supplier Selection Process

Ho et al. (2010) carried out a comprehensive review of the various forms of operationalising the supplier selection process and found it to be dominated by two methods: analytical hierarchy process (AHP) and data envelopment analysis (DEA).

AHP is a robust method for developing relative importance weightings for selection criteria through pairwise comparisons. In particular, AHP addresses the inadequacies of human judgement when faced with multiple criteria. The basic foundation of the technique is the consistent derivation of weights based on the comparison of each criterion with all others. In a perfect world free from judgement, the total importance of all criteria can be summed to some value, with each criterion making a specific contribution. Formally this can be stated as:

AHP adopts this formulation but accepts that human judgement is not always consistent or coherent. The technique then uses a robust (and mathematically complex) means by which it establishes the consistency of the pairwise comparisons. It is not important here to describe in detail the method as it is not the core of this research and in any event will be returned to in more detail in subsequent chapters.

Having established the relative importance of weightings for each criterion a buying organisation is faced with the task of establishing how all potential suppliers perform in terms of satisfying the selection criteria.

3.2.5 Summary

In summary, supply risk and item criticality combine to define the context for the development of supply strategy. The development of supply strategy as described by Kraljic (1983) is broadly supported by the previously described theories of TCE and SET.

The drivers of supply risk are uncertainty and dependency. Dependency also drives the network dynamics, which is a source of uncertainty, thereby placing dependency at the centre of any supplier switching consideration.

Suppliers are selected using a range of multiple criteria which can be categorised as: price, quality, financial stability, flexibility and delivery. Methods used to execute the supplier selection process have been developed by calculating th relative importance weights for each of the supplier selection criteria and then assessing the performance of each alternative supplier against these criteria to develop a supplier score and ranking. Such considerations can range from relatively naïve (not considerate of supplier cost inputs and therefore efficiency) to sophisticated (considerate of supplier cost inputs and therefore efficiency).

Increased dependency is considered a means of stabilising a relationship, and this building of relational inertia contributes to the critical organisation of the supply network. Furthermore, the increased dependency deliberately engineered at the dyad level increases vulnerability to opportunism and therefore requires a deeper development of trust and commitment, resulting in further relational inertia. Therefore, dependency is theoretically the foundation of emergent behaviour within supply networks, and a contributor to potential disruptions as described in Chapter 2.

Whilst the literature reviewed so far reveals the theoretical foundations for market organisation, the design of relationships, supplier selection, and supplier switching falls short of describing the process of operating the network embedded relationships to secure supply to sate demand. The next section will therefore consider the analytically derived principles that define inventory management and the operation of a supply chain.

3.3 Normal Operations and Normal Adaptation

The previous sections in this chapter have examined the literature pertaining to the organisation of supply, supply strategy, and supplier selection. Whilst these constitute normal operations they are devoid of any descriptions of transaction mechanisms, on which the fundamental operation of a supply chain is reliant. The anchor point for material, cash and information transactions across organisational boundaries is the management of inventory, with the purpose of securing product availability at the greatest economic efficiency given the constraints of strategy and supply alternatives (Kraljic, 1983; Waters, 2003).

Inventory management is the fundamental task of the supply chain as it incorporates the tasks that: 1) ensure service levels are sated; 2) availability meets expectations; and 3) appropriate levels of responsiveness are secured. Its efficiency is the focus of supply strategy, its prioritisation underpins supplier selection, it is the material accommodation of uncertainty, and the life blood of relationships. Inventory management is conceptualised in Figure 3—12.

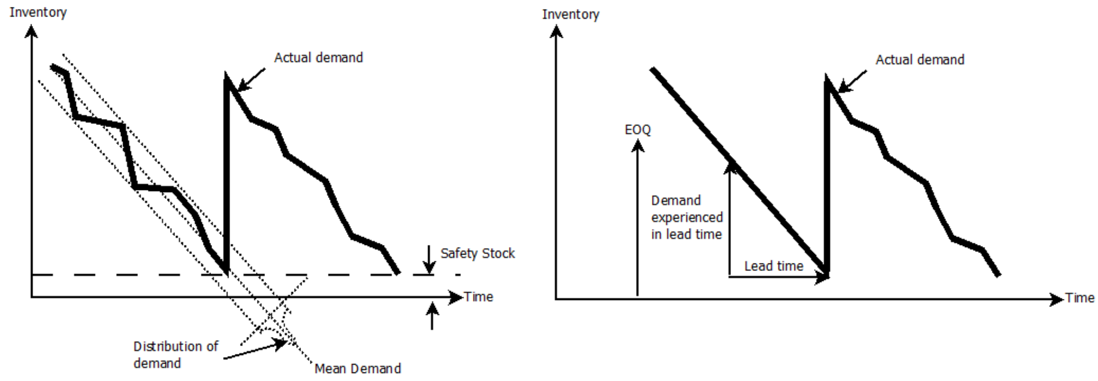


Figure 3—12: Inventory management

Figure 3—12 shows that even if demand is variable, providing that it follows some stochastic pattern it can be incorporated into a predictive model that ensures a product is ordered from suppliers in sufficient quantities and in a timely manner which ensures sufficient inventory is available to sate the variable but predict demand patterns. Figure 3—12 shows that variations in demand can only be accommodated by increased inventory buffers.

The essence of the inventory management literature is that given enough information it is possible to precisely formulate the levels of stock to buffer uncertainty, how much to order, and when to order. Waters (2003) amongst others draws on the analytical derivation of formulaic descriptions of economic order quantity (EOQ), safety stock, and reorder levels, given a set of reasonable assumptions. These assumptions include: 1) demand that is independent, 2) the nature of demand (certain/uncertain), 3) fixed costs, 4) lead time, and 5) prices that are fixed and independent of quantity ordered. Table 3-9summarises the formulaic descriptions of EOQ, safety stock and re-order level.

Table 3-9: Formulaic descriptions for EOQ, safety stock and re-order level

Safety stock	$safety\ stock = 1.65 * \sigma_{demand} * \sqrt{LT}$
EOQ	$EOQ = \sqrt{\frac{2 * RC * D}{HC}}$
Re-order level	$ROL = LT * D$

The assumption that demand is independent infers that the demand for a particular product is not dependent on other products or considerations. In other words, independent demand refers to a context where the product being considered is not a component of some other product whose demand would determine the demand for the component product.

Dependent demand means that the demand for a particular product is dependent on the demand for some other product with which the first product is associated. This association may be that the first product is a component of the second, whilst other associations may be that demand for a product is amplified or dampened depending on the level of demand for another product (the so called halo effect). If associations are explicit then the association can be incorporated into what becomes a more elaborate formulation than those detailed in Table 3-9.

Whether demand is dependent or independent the understanding and interpretation of demand signals is a critical component of inventory management. Forecasting methods are often used to predict demand variations as a result of trends or seasonality; however, it is generally recognised that such approaches can do little to anticipate the consequences of competitive action such as price reductions (Marshall , 1930). Competitive actions beget responses and thus the perpetual cycle of co-evolution develops (see previous chapters).

In its simplest form forecasting uses historical experience to predict future experience based on assumptions about seasonality and whether or not the demand is dependent or independent. The analysis can assume various levels of sophistication, with at one extreme moving average calculations, and at the other trends projection methods. In the absence of any other inputs previous period demand is a reasonable indication of the next period's demand. However, this naive assumption (that there are no dynamic influences on demand) does not allow for competitive action designed to modify the allocation of demand across competitive organisations. As already discussed, competitive action is autonomous and across a network many organisations will exercise what influence they can on the allocation of demand in parallel to other organisations competitive actions.

The frequency of organisational interventions designed to increase demand describes the volatility of a market and it is generally recognised that volatile markets (with many competitive parallel interventions) are difficult to forecast. Competitive action is not the only source of demand volatility: customers may be able to substitute alternative products or the utility of a product may be surpassed by technological innovation, equally demand may be modified by regulations or policies.

These factors are a consideration in the generation or design of strategy, however tactical and operational responses constrained by an organisation's cost structure are largely focused on price adjustments.

If product innovation and substitution are controlled, tactics dictate that short-term future demand will be a reflection of recent historical experience. The inventory needed to sate fluctuations in demand has already been shown to necessitate increased inventory holdings, however the amount by which the inventory is increased can be minimised at the supply chain level by following two principles: 1) centralise inventory holdings at a point as close as possible to its manufacture given time and distribution constraints; and 2) leverage product modularity and configurability to postpone specific configuration as long as possible given time and distribution constraints.

The minimisation of supply chain inventory holdings requires that information be traded for inventory, in other words if consumer demand is shared with manufacturers a supply chain can be confident that the manufacturer will carry enough inventory to sate demand. Furthermore, the manufacturer can then accept the cleanest demand signal (devoid of order batching noise as described previously by the bullwhip effect), thereby ensuring the system holds the minimal inventory to accommodate true demand fluctuations. Unfortunately, the strategies described here load inventory into particular components of a supply chain, inferring that these components will not enjoy the same benefits of inventory reduction and the associated holding costs as their upstream and downstream partners. This has been shown to be a major inhibitor in efficient supply chain wide inventory management (Ford et al., 1986; Bastl et al., 2010; Cambra-Fierro and Polo-Redondo, 2008; Hausman and Johnston, 2010; Jorde and Teece, 1989; Kim et al., 2010)

Despite the inhibiting effect of the inequitable distribution of benefits across a supply chain, information sharing is still a vital component of efficient supply chain operation and inventory management.

In summary, there is very wide acceptance of the formulaic description of how inventory can be managed and the role information sharing has in the efficient operation of a supply chain and the resultant flow of materials.

The next section will draw the previous sections in this chapter together to develop an operational framework of buyer supplier relationships and relate these to the operation of a supply chain, before positioning these in a supply network framework, thus providing a robust foundation for the specification of an appropriate research design to answer the research questions formed in this chapter and in Chapter 1.

3.3.1 Operational Framework

The purpose of this chapter was to examine the extant literature to establish a framework describing the normal operation of supply chains. Thus far the chapter has examined the motivation of firms to form relationships, the design of these relationships, the risks associated with partner behaviour/uncertain demand, the mitigation of these risks, and the management of inventory. This section will begin by examining existing supply chain management with a view to synthesising a framework appropriate to the questions posed in this thesis.

Juttner et al. (2010) identified three types of supply chain management frameworks: inter-functional, process integration, and business concepts. Functions are discrete organisational components that are designed for a particular purpose, for instance logistics is primarily concerned with the movement of materials. Inter-functional frameworks primarily address the interface between functions, e.g. how logistics interfaces with marketing to anticipate and organise activity around promotions. Consequently, the inter-functional level of supply chain management is largely a consideration of intra-firm activities.

Frameworks that address processes are devoid of organisational boundaries and have become the focus of supply chain management literature. Cooper and Lambert's (1998) framework has been previously described, and it established seven (widely supported) supply chain processes which facilitate the movement of materials across a supply chain (see Table 3-2):

Business concept frameworks set the strategic agenda for the supply chain perspective adopted within and across firms. For instance, a firm adopting an agile business concept in response to variations in demand will design inter-functional interfaces that enable inter- and intra-firm processes to respond quickly to any changes.

The organisation of inter- and intra-firm activity at the inter-function and process levels of organisation is contingent on context, and its operationalisation must therefore include some sensing of the environment. Cooper and Lambert's (1998) framework is presented in Figure 3—13 and is generally representative of the holistic approach to the supply chain framework.

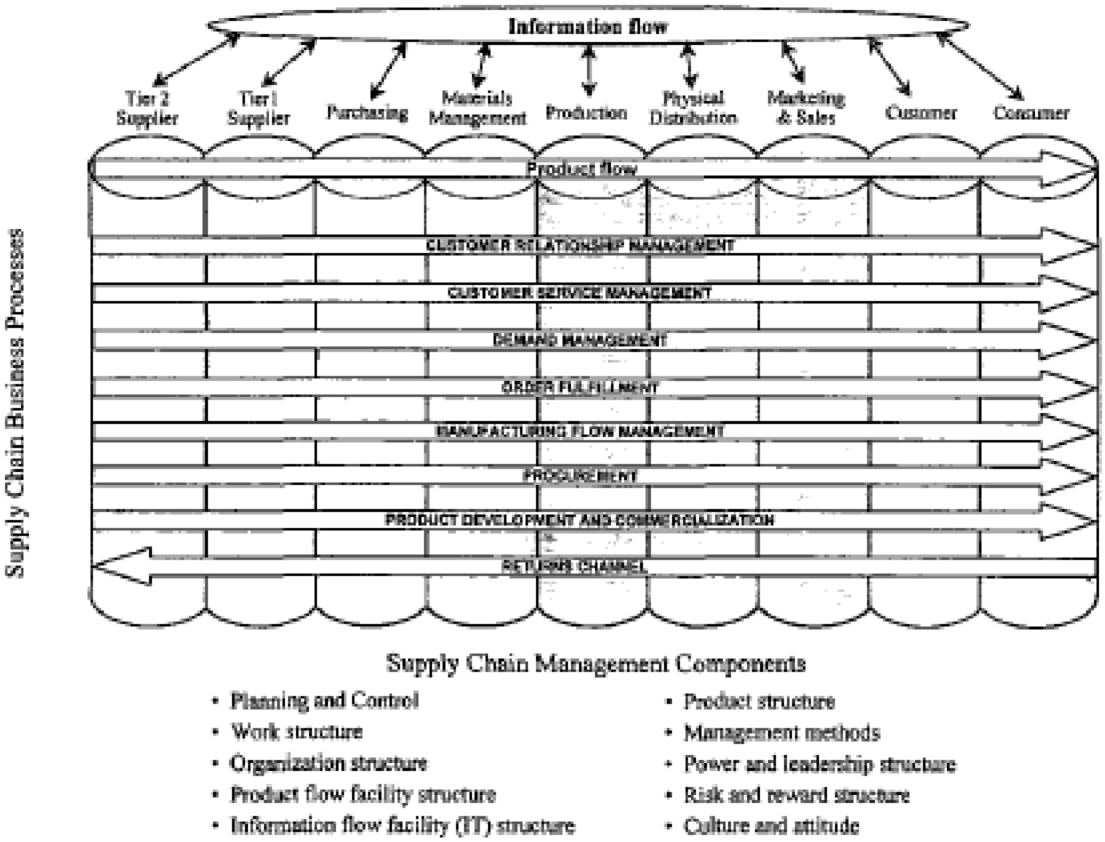


Figure 3—13: Supply chain framework

Source: Cooper and Lambert (1988)

The supply chain framework has five intra-firm functions, nine inter-firm processes, and ten management components. This thesis is concerned with inter-firm relationships and assumes intra-firm functional integration; management components are activities and attributes that span all multiple business processes.

From the perspective of mapping normal supply chain processes relevant to this thesis, the framework processes need to be unpacked and the process components examined for relevance to the phenomenon of interest with the purpose of identifying potentially simplifying assumptions. Table 3-10 summarises the content of each component relevant to each of the processes specified by Cooper and Lambert (1998).

Table 3-10: Components of normal supply chain processes

<table>
<tr><th>Process / Components</th><th>Customer Relationship Management</th><th>Customer Service Management</th><th>Demand management</th><th>Order fulfilment</th><th>Manufacturing flow management</th><th>Procurement</th><th>Product development</th></tr>
<tr><td>Planning and control</td><td>Organization of relationships based on dependency</td><td colspan="2">Information sharing and cooperation to minimise inventory and secure service levels</td><td rowspan="4">Information sharing enabling inventory Management</td><td colspan="2">Identifying dependencies and organising relationships accordingly</td><td>Inter-functional and inter-organisational teams</td></tr>
<tr><td>Work structure</td><td colspan="3">Levels of integration based on context and dependencies</td><td colspan="3">Levels of integration based on context and dependencies</td></tr>
<tr><td>Organisation structure</td><td colspan="3">Degree to process dominates function – dependent on relationship configuration, cultural alignment</td><td colspan="3">Degree to process dominates function – dependent on relationship configuration, cultural alignment</td></tr>
<tr><td>Product flow facility structure</td><td colspan="3">Distribution channel infrastructure and network design</td><td colspan="3">Supplier selection and management</td></tr>
<tr><td>Information flow facility structure</td><td colspan="7">Information sharing</td></tr>
<tr><td>Product structure</td><td colspan="3">Degree to which customers are involved in product design</td><td>Enablement of postponement strategies</td><td colspan="2">Degree to which customers are involved in product design</td><td>Partner involvement in product design</td></tr>
<tr><td>Management methods</td><td colspan="3">Adaptation to secure increased attractiveness to the market</td><td>Buffering against uncertainty</td><td colspan="2">Adaptation of supplier selection criteria</td><td>Product life cycle</td></tr>
<tr><td>Power and leadership</td><td colspan="3">Dependency driven acquiescence</td><td rowspan="2">Strategic location of inventory</td><td colspan="3">Coercion vs collaboration</td></tr>
<tr><td>Risk and reward</td><td colspan="3">Commitment to customer and self-interest balance</td><td colspan="2">Commitment to Supplier and self-interest balance</td><td></td></tr>
<tr><td>Culture and attitude</td><td colspan="2">Alignment with customer</td><td colspan="2">Alignment with customer and degree to which cooperation enabled</td><td colspan="2">Alignment with supplier</td><td>Partner involvement in product design</td></tr>
</table>

An examination of Table 3-10 reveals that in the interest of parsimony and clarity, some simplifying assumptions can be considered.

Product development can be controlled in terms of only considering the supply chain operation for a single durable product that is not replaceable. This assumption also removes the problem of dependant demand (where a product's demand is dependent on the demand of the product in which it becomes incorporated). Such complications are best examined once a basic framework for the examination of such factors has been established and some theory developed which can be tested. In a similar vein the product structure can be assumed to be given and assumed not to render any opportunity for postponement.

Further examination of the table allows logical arguments to be developed in regard to the treatment of organisation structure, information sharing, management methods, power and culture. These management components are emergent and a consequence of a firm's risk perceptions/experienced uncertainty. Planning and control is therefore the key management component that sets the context for the business process, primarily through the organisation of relationships in terms of trust commitment, cooperation and information sharing, all of which are again dependent on perceptions of dependency/risk and uncertainty. Context therefore defines the organisation of relationships and these define the nature of the remaining management components which define all business processes. The path dependencies described above are summarised in Figure 3—14.

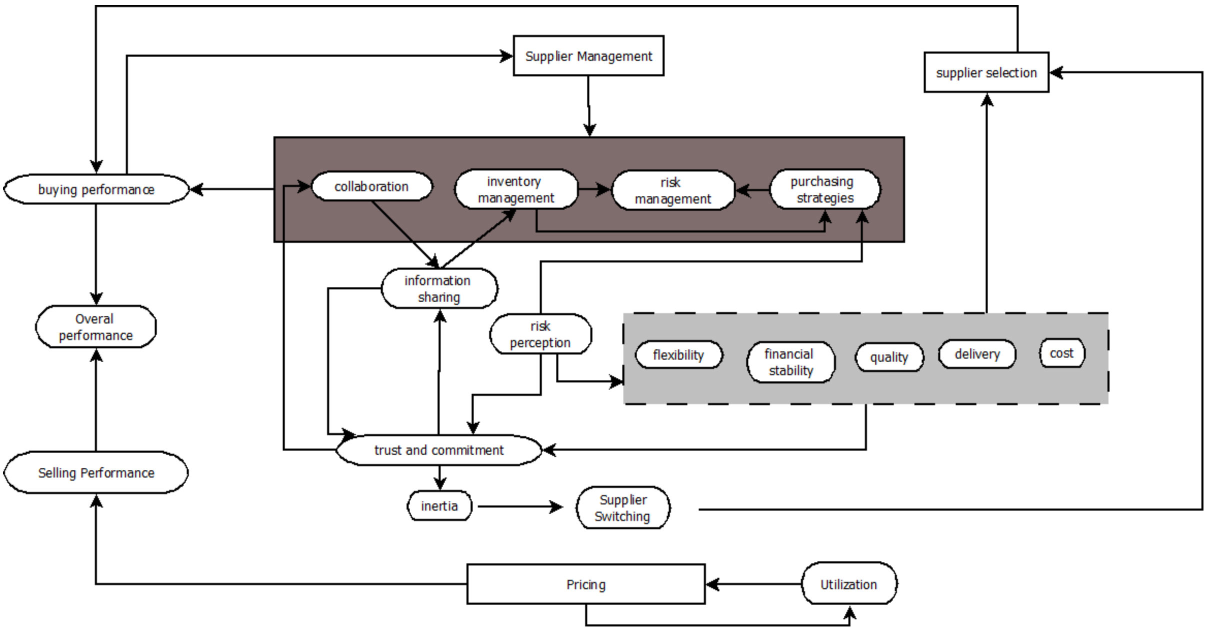


Figure 3—14: Path dependencies of supply chain processes

The logical extension of these arguments, which incorporate the simplifying assumptions stated previously, is the development of a set of simple rules. The interpretation and execution of these define an organisation's operations within a supply context, specifically organisations should:

1. Assess context in terms of uncertainty and supply risk – this drives the prioritisation of supplier selection criteria, develops purchasing strategy and determines the appropriate level of trust and commitment
2. Specify supplier selection criteria weightings based on context
3. Select suppliers taking account of context and associated prioritisation of supplier selection criteria
4. Assess attractiveness to the market and modify price to increase/decrease attractiveness
5. Manage inventory in accordance with relationships formed, experienced risk/uncertainty, and information shared

The essence of this argument is that if autonomy is assumed and a CAS perspective adopted, then each firm assesses its context to design its relationships with suppliers selected against specified weighted criteria. The nature of the relationships developed influences the level of information sharing, and impacts direct forecasting and responsiveness, thereby enabling a reduction in inventory. Supplier and customer relationships are constantly experiencing perturbations because of the adaptive nature of firms to act in self-interest.

3.4 Summary

Chapter 1 provided the background and motivation for this research in the form of a problem statement. Chapter 2 provided a theoretical framework and anchor for the conceptualisation of disruptions as a consequence of normal operations, and Chapter 3 has provided an operational model based upon a set of justified assumptions.

The remainder of the thesis is concerned firstly with the design of an appropriate research approach, and then details of the research undertaken. The next chapter will outline some of the ontological and epistemological frames that shape the research design.

4 Methodology

4.1 Introduction

The previous chapter provided a theoretical foundation for the positioning of supply networks as CASs with the behaviours of firms being described by supply chain management practice anchored in TCE and SET. In so doing the literature review exposed gaps in the extant knowledge relating to our understanding of the dynamics of supply networks generated by autonomous actions in conditions of bounded rationality.

This thesis is particularly concerned with how those dynamics may or may not generate vulnerability to disruptions, which previous chapters surfaced by considering normal accident theory and its application to CASs in the context of supply networks.

The theoretical foundations and gaps in extant knowledge have been used to frame the central question of this research:

> *How do network structures evolve to develop or dissipate sources of network risk as a consequence of normal supply chain operations in the context of competing risk and competitive advantage seeking strategies?*

The previous chapter framed the purpose of the research with three further research questions:

1. *Do supply networks comprising multiple connected supply chains experience periods of disruption as a consequence of normal operations?*

2. *What is the impact of market structure on the level of disruption experienced by networks?*

3. *What is the impact of adaptation and collaboration between supply chain participants on the level of disruption experienced by a network?*

The dynamics of supply networks have previously been argued to rest upon individual firms' perceptions of supply risk reflected in dependency and uncertainty. As a consequence, the initial conditions and in particular the population profile can be argued as important in determining the possibilities for re-organisation of a network. A population profile can be expressed in many ways but in the context of supply strategy and supplier selection, the important dimensions are: size of population, differentiation of population and the roles (e.g. retailer, wholesaler or manufacturer) of the population.

The roles of the population allow the population size to be fragmented according to the populations' purpose, and in this way it is possible to describe the scarcity of supply experienced by each role. In a similar vein, differentiation across a population (defined by its role) is a reasonable indicator of how a network may evolve: low differentiation means it is unlikely that a network will become over dependent on any one supplier, whilst high differentiation suggests the possibility of many buyers choosing the same attractive supplier, thereby developing a high dependency on that supplier.

The impact of initial population in terms of size and differentiation develops a set of parameters that must be considered in answering the research questions posed.

Further parameterisation of the problem space can be developed from a consideration of firms' behaviours in terms of how firms choose to respond to risk, the degree to which they collaborate, and their strategies for competition. These behaviours rely on a firm's unique interpretation of their context, but it has already been argued that systems that permit some or all of these behaviours result in different structures.

Finally, the degree to which incumbent organisations can be challenged by new entrants is a reflection of the barriers to entry, and as such this presents another parameter which could play an important role in the emergent dynamics of a network.

By framing the research questions in a parameterised problem space any subsequent research into this phenomenon specifies a skeletal research design framework. By incorporating these parameters into any methodology it is hoped that the research will reveal the major factors that influence supply network vulnerability to disruptions. The remainder of this chapter starts by summarising the previous chapters to provide the context for the development of an appropriate strategy, consideration will then be given to the ontology and epistemology of the phenomenon of interest, before considering suitable methodologies. The chapter concludes by specifying the approach to be taken.

4.2 The Nature of Networks - Ontology

In order to develop theory researchers have to make clear the perspective they have adopted, its alignment to a particular ontology, and an epistemological justification that reflects perspective and ontology.

There are three classic perspectives describing the range of philosophies adopted in the development of organisation theory: modernism, symbolic interpretivism and post-modernism. Modernism is essentially a positivist philosophical perspective that assumes reality can be observed independent of the observer, whilst symbolic interpretivism relaxes positivist constraints and allows reality to be a construct formed from the observer’s/observed unique view of the world. Post-modernism takes a constructivist perspective where reality is persistently being recreated by the interpretations of its constituents, and like symbolic interpretivism it is dynamic and defies any objective definition, but can be distinguished by the level of fragmentation and privilege to any particular narrative.

There are a number of theories drawn from each of these perspectives that have been posited to understand how n organisation relates to its environment and therefore these are relevant to this thesis which is focused on the interaction of organisations with their environment described by a population of other firms with competing and complementary roles.

Modernists’ adopt a positivist view of the world which assumes reality/truth is external and observable independent of the observer. Within this perspective networks of relationships can be discovered and observed allowing analysis which can characterise firms into cliques. Typically research adopting this perspective is concerned with the global observations of mortality and birth rates of firms – a god like view of the world - leading to understanding of what strategies or clique wide strategies are more or less successful. Any explanation of why the pattern of strategies a firm develops assumes that each firm has a common and complete interpretation of context. Clearly this philosophy does not accept bounded rationality, which constrains our understanding of inter-firm relationships to at least understanding the world as perceived by each firm.

Ecology theory adopts a modernist perspective and is concerned with clusters or cliques of organisations fulfilling particular roles within a network environment. The population of a clique is described in terms of the mix of strategies produced in seeking improved clique performance. As such it is inevitably concerned with the fitness of individual firms constrained by their context to develop successful strategies; however, the modernist perspective puts aside considerations of how each firm uniquely views its own context instead preferring to assume global descriptions and reverting to an observable reality.

Ecology population theory can therefore be framed as describing the macro patterns of behaviour that are likely to benefit a population or clique. However, the mechanics of how this macro environment is developed are more difficult to embed within this framework as each firm has a unique perception of its own context. This point is particularly emphasised if conditions of bounded rationality are accepted as described in previous chapters relating to TCE and SET.

The modernist perspective is not entirely constrained to ecology population theory but also accepts that firms interact with their environment in terms of dependencies to access resources or markets for their products. This dependency of a firm is captured by resource dependency theory, but just as ecology population theory neglects a firm’s unique interpretation of their environment resource, dependency theory neglects how the actions of a firm changes environments.

The major criticism that can be levelled at the modernist perspective is that it neglects the perpetual complex macro-micro interaction dynamic.

Symbolic interpretivism challenges the modernist perspective. Firms have a unique interpretation of their context which is based on bounded knowledge which determines their actions. In particular, enacted environment theory posits that a firm's interpretation of context can be characterised in terms of uncertainty and actions to reduce uncertainty. Firms affirm their interpretations through the way they act and their interpretations of their actions, for instance a firm that perceives its environment as risky acts to mitigate the risk and interprets the consequences of its actions as validation of the original interpretation. Enactment theory therefore reflects the emergent nature of relationships, as Karl Weick (1979)noted:

> *“Enactment creates contingencies as well as events. The initiating conditions seem small in comparison to macro events only because these examples articulate the local turning point, the point of bifurcation, the moment of initiation. These triggering moments often serve to implant small but uncontained outcomes in larger systems. These embedded, uncontained outcomes continue to grow undetected until they spawn unanticipated consequences.* “ (Weick, 1979, p.188)

Enactment theory is largely limited to a single consideration and it does not extend into chains of enactment or their consequences (1999) and others have epistemologically framed complex systems as evading detailed linear deterministic descriptions but not without patterns and structure which can be observed and characterised. The ontological implication is that the patterns will be dependent on permitted behaviours which will colour interactions and set system conditions. To uncover relationships between observable patterns and permitted behaviours, of which there can be many, requires abstraction, and more importantly experimentation.

I believe that supply networks are formed from the autonomous uncoordinated actions of firms executing the process of seeking suppliers to secure resources vital to their own operations. A network is not static because the objective of each firm within a network is to secure the greatest possible performance (often naïvely) by adapting their character to make them more attractive to others. The cumulative effect of all firms adapting all of the time is a network which perpetually changes. Furthermore, a network is not closed or predefined, instead it is open to new entrants to challenge the incumbent's and existing firms will exit a network if they do not perform satisfactorily. A network therefore is driven by individual firms' motivations requiring perpetual adaptation from focal firms and those that surround them, whilst being open to challenges from new entrants, which may or may not cause existing firms within the network to exit due to unsatisfactory performance.

The ontological interference of this is that network structures are emergent but observable and that the structures at any point in time will be the same regardless of the observer. In other words, there is an external truth regarding network structure to be discovered or observed at any point in time. However, our knowledge of how the structures are created can only be developed through consideration of the actions of individual firms founded on motivations that can only be understood through the eyes of that firm and their perceptions of their own context. These are not external truths but rather are internal interpretations made by the organisations regarding their observations of their context. This results in a structural complexity which is objective whilst the understanding of how this objective structure developed requires us to understand subjective interpretations made by the firms existing within networks. The CAS's perspective, previously described in Chapter 2, posits that the observable objective network structures are a consequence of autonomous subjective actions based on interpretations by individual firms using a few simple rules. In other words, simplicity can generate complexity if actions are autonomous and subjective.

The remainder of this chapter is therefore concerned with firstly examining the literature describing methodologies suitable for CASs, before developing a logical argument in support of the chosen methodology.

4.3 Autonomous Behaviours and their Theoretical Anchors

The legitimising of any methodology can only be secured through its grounding in robust ontology and adequate reflections of epistemological considerations, in the context of this thesis these have been summarised in the previous sections of this chapter. However, the ontological and epistemological considerations of the previous section draw significantly on the existing theories relating to supply decisions, their motivations, and their operationalisation. Consequently, this section draws on the existing theory to anchor the constructs that underpin the epistemological framework.

There is fairly common agreement in the literature regarding what theory is: constructs, linking propositions, logical arguments/explanations, and assumptions that define the scope of the developed theory (Dubin, 1976; Sutton and Staw, 1995; Whetten, 1989). Theory is therefore the glue that secures the relationships between variables, but it must be testable and grounded in data/argument.

If theory is indeed composed as described above, a reasonable starting point for the development of any theory is the situating of current constructs, linking propositions, and assumptions in a conceptual model (see Chapters 2 and 3). In doing so, the contribution made by answering the research questions can be contextualised.

The incorporation of these constructs into an epistemological consideration requires that we understand both the maturity/robustness of the theoretical anchors for a conceptual framework and the degree to which these conceptualisations have previously been applied to supply networks. In so doing the level of supply network conceptualisation is illustrated and the benefit of using these theories in new epistemological contexts is established as a sound methodological approach to build on existing theory.

4.4 Maturity of the Existing Theory

The maturity of existing theory can be assessed along two dimensions: degree of saturation, and clarity of constructs, linking propositions and logical arguments. Mature theory has been exposed to many contexts and its predicting/explaining power has therefore been widely tested yielding a robust grounding in both logical arguments and empirical evidence. Immature theory, otherwise described as simple theory (Davis et al., 2009), seeks robustness through testing and development. In this context there are a number of logically argued challenges regarding the clarity of the network/CAS concepts presented previously, specifically: conceptualisation of a network; lack of understanding of the interactions (weak dynamic descriptions); and a paucity of empirical evidence

4.4.1 Conceptualisation of the Network

Several conceptualisations of a supply network can be found in the extant literature, which in broad terms can be differentiated by whether or not they accept a focal firm perspective. Harland (1996) and Choi (2002) are both examples of research that assumes a focal firm perspective, defining the network as a tree like structure with a focal firm having many customers and suppliers within any specified tier. Critically, this approach does not consider the influence of adjacent supply chains, and therefore excludes competitors to the focal firm. These conceptualisations have been previously presented in the literature review.

The focal firm definition of supply chains also fails to address any arguments regarding irreducibility. The CAS's perspective posits that interactions between systems are a key determent of system behaviour; by excluding inter-chain interactions much of the supply network conceptualisations are merely an extension of the supply chain paradigm, an observation supported by Harland (1996) and Choi (2002; 2001b).

The argument that it is necessary to extend the supply chain horizons, and this has led to the development of tree like structures that include more and more participants as the relationships grow ever distant from the focal firm. However, the tree like structure is still defined by a focal firm, and as such it still excludes any of the focal firm's competitors, who by logical argument are likely to share the focal firm's suppliers/customers.

Carter et al (2007) stands alone in the literature as they developed a survey approach to defining a real-world network with no focal firm. However, such an approach is inevitably limited in its consideration of the network dynamics, as it can only ever represent snapshots of the network organisation.

The logically argued and empirically supportable argument that real-world research into network behaviour is limited by access to meaningful data has drawn many researchers to computer simulations as the means by which networks of interacting supply chains can be used to develop formative theory. Such formative theory should be more testable with real world data as the developed theoretical frameworks provide structure to real-world empirical research designs that would otherwise remain elusive.

4.4.2 Dynamic Nature of Networks

The emerging body of literature that uses computer simulations to develop contributions to supply network knowledge and theory generally adopts a non-focal firm perspective. However, there is no dominant framework that addresses the dimension of dynamics. Generally, computer simulations accept the concept of parallel actions; however, some place these in static structures that have no structural adaptive capability, whilst others relax this constraint allowing the network to reorganise within the constraints of a specified population. Further ambiguity emerges when computer simulations incorporate dynamic populations, i.e. they permit new entrants and accept exits of poor performing firms.

The body of literature that describes networks from a focal firm perspective, by its very nature, assumes that firms are immortal within the temporal boundaries of their consideration and unaffected by competitive action. This reduces the system to one that is largely static and in a state of neo-equilibrium. These conceptualisations are useful as they provide insights into the relationships between organisations in the context of static environments. However, they offer little in understanding the real dynamics of networks that embrace firms exiting and entering the system and the consequential re-organisation of relationships.

Pathak (2007a) highlights two decision making themes:

> *"Two emergent themes that managers frequently encounter when making these decisions are (i) the structural intricacies of their interconnected supply chains* (Choi and Hong, 2002) *and (ii) the need to learn and adapt their organization in a constantly changing environment to ensure its long-term survival* (Eisenhardt and Brown, 1998)*"*

The first of these points directs us towards a consideration of the interconnectedness of networks at all levels, highlighted by the broad categories of supplier selection criteria highlighted by Weber (1966): quality, price, financial stability, delivery/geography, and flexibility. By way of illustration, it is not difficult to logically argue that financial stability is related to a firm's consistent attractiveness to its suppliers, this in turn infers that it is willing to participate in appropriate relationships determined by its context and that of its customers, and financial stability implies good utilisation of assets which impacts a firm's ability to price assertively.

Within this myriad of connectedness there emerges a number of feedback loops, adding to the validity of a CAS perspective being necessary when considering supply networks. For instance, in seeking superior performance a firm aims to adapt its operations in ways which make it more attractive to its customer base, and if effective, this will generate disturbances/disruptions which will generate a new back drop requiring further adaptation.

The interaction of processes within a firm and across the broader network structure is the base mechanism in the generation of firm adaptation, which in turn is the base mechanism in generating network dynamics.

The intra-firm process interactions adopted in this thesis have been previously argued and presented, and are anchored in supply chain theory/practice. By allowing these interactions to generate network dynamics and not constraining firm behaviour to externally imposed design, the network participants are free to try and evaluate new formulations of established processes.

There is an emerging body of literature that is starting to address the open nature of real world supply networks (Pathak et al., 2007a; PATHAK et al., 2009; Pathak et al., 2007b; Brintrup, 2010; Datta and Christopher, 2011b). These approaches generally accept that organisations will depart from a supply network when they exhaust their cash supply; however, they do not generally accept the possibility of new entrants to a network. From an ontological perspective this is clearly problematic when considering the long term behaviour of a supply network.

Given that there has been little theory development regarding the dynamic behaviour of supply networks, it is no surprise that what empirical grounding exists it takes a bounded focal firm perspective.

4.4.3 Paucity of Empirical Evidence

The focal firm description of supply networks contrasts with networks that have no focal firm. Carter et al (2007) present what is one of only a few examples of empirical evidence gathered from surveys to describe a supply network that has no focal firm perspective. However, the snowballing method adopted by Carter et al's (2007) research obviously takes a focal firm for its starting point. As well as demonstrating how empirical network data may be collected this research also demonstrates a limitation of this approach in understanding/describing network dynamics.

4.4.3.1 Summary of the Maturity of Extant Theory

This thesis will adopt the broadest definition of a supply network that incorporates a ‘no focal firm perspective’, dynamic structures created by network participants’ supply chain decisions, the challenge of new entrants, as well as the exit of poor performing organisations. In this manner the research will embrace the main dynamic mechanisms of a network and minimise the criticism concerning over simplification that has been levelled at computer simulation approaches to developing theory (Pathak et al., 2007a).

Assimilation of the above situates the extant theoretical base as applied to networks as what Davis et al. (2009) describe as simple theory: useful but not complete.

4.5 Barriers to Further Theory Development

For theory to be robust it should have been thoroughly tested, assumptions clearly stated, and be grounded in both logical arguments and empirical evidence. As already described, this presents a number of epistemological challenges against which any methodology must be judged, specifically:

- It must grounded in an existing theoretical base to accept the phenomenon of interest, i.e. it must extend the focal firm’s perspective and include adjacent supply chains and the associated concepts of dynamic competition and connectedness.
- It must be supported by sound logical arguments developed from extant knowledge and which support any assumptions made.
- Any logical arguments should be supported by empirical evidence or strong logic.

Given the above, this thesis will seek to develop methodologies that build on existing theory, thereby enriching and deepening our understanding of supply networks. By extension, the adopted methodology will also make more robust the extant theories and in so doing will improve the partial answers to the research questions that could be deduced/argued from extant knowledge and theory.

The next section will consider generic approaches that could be suitable for developing supply network theory given the ontological, epistemological, and extant theory constraints.

4.6 Methodologies Suitable for Building Supply Network Theory

Theory can be built inductively and modified by deductive testing, and therefore follows an evolutionary path of refinement resulting in robustness and ultimately (one hopes) saturation, where no further improvements to the theory can be established.

The ontology previously described presents a number of epistemological challenges: how to define the boundaries of a network; the difficulty in developing data spanning appropriate timescales; the incorporation of new entrants to the market; the difficulty of measuring social friction/collaboration/inertia; and the difficulty in developing appropriate controls for variables.

Unlike supply chains which have definitive beginnings and endings (conceptually raw materials to customer consumption), networks embrace orthogonal dimensions which reflect the boundless connectivity of supply chains with other supply chains through shared customers and suppliers. Although not directly related to supply chain or network systems, the social phenomenon generally described as the six degrees of connection highlights the boundless nature of networks.

The empirical data used to inductively build the six degrees of connection theory was drawn from the informal delivery (by hand and without the use of an organised postal system) of postal packages to random addresses across the US. The delivery process was constrained to individuals passing the packages to people who they thought could connect better to the destination address. Each time the package was handled a signature was collected, and when the package arrived at its destination the addressee was invited to return it with the details of the handling signatories. The experiment showed that over a very large sample no package was handled more than six times.

Although this experiment does not take into account the strength of any connections used or exploited to deliver the package, it clearly demonstrates that the social world is at least highly connected. It is also logically possible to argue that the industrial world contains a much greater differentiation of connectivity to the social world, that is to say the world of business is dominated by a few large organisations who could act as distributing hubs that any packages being passed from one industrial enterprise to another would have to pass through. In this sense it may well be the case that the industrial world is more connected than the social world.

Collecting empirical information regarding supply networks that span the globe represents a daunting, if not impossible challenge. If it was possible to identify the participants in supply networks then the next challenge would be the collection and organisation of data spanning considerable timescales reflective of the potential propagation of disruptive processes rooted in the inertia of long term contracts or other equivalent relational considerations.

The robustness of any explanations regarding supply network re-organisation needs to consider the potential interaction between state variables, processes, and how these are modified by inter-firm activity. It is therefore necessary to develop a methodology whereby these variables and processes can be controlled in an experiment. This is clearly not possible in any real world context.

The epistemological challenges described above have proved major barrier to inductively building empirically grounded theory relating to supply networks, but have also been the catalyst for increased research in the field using computer simulation techniques.

In generic terms, research into supply network operations has generally taken three forms: definition of a network and its behaviour using survey methods (Carter et al., 2007) computer simulations of constrained networks, usually defined by a single organisational boundary; and computer models that are not as constrained but also not as robustly anchored in the real world as the other two approaches.

The following sections will consider each of these approaches in the context of the research questions and the associate ontological and epistemological imperatives.

4.6.1 Empirical Studies to Build/Test Theory

Empirical data can be used to satisfy two purposes in the context of theory: it can be used as the base from which theories are inductively created or it can be used as a means of deductively testing/modifying/extending existing theory.

Earlier sections have argued the case for networks to be considered from the constructive relativism perspective, with firms interpreting their context and making autonomous decisions that reflect this interpretation and their belief system. These decisions interact with other connected firms' decisions from which a network structure emerges. Such a theoretical perspective finds a natural home in the theoretical domain of CASs, and presents significant barriers to the collection of empirical data as a network is considered boundless, irreducible and perpetually changing.

A well designed research approach based on empirical data has the benefit of robust verifiable foundations for its findings; however, its application is usually constrained to the data context from which any theories have been developed. Such approaches are nevertheless vulnerable to criticisms of being overly constrained as they preclude the possibility that an entirely different reality may have emerged had the initial conditions been only marginally different. This vulnerability is particularly troublesome when the theoretical perspective used as the basis for any developed constructs is so reliant on such possibilities (i.e. CASs).

Within the context of supply networks it has been argued that survey based approaches, such as those used in social network analysis, have applicability to the collection of data in supply networks (Harland, 1996; Choi and Hong, 2002; Choi et al., 2001b).. Such surveys rely on organisations being able to identify what relationships they participate in and with whom. The survey can then be deployed in a snowballing method, whereby identified network participants are asked to identify other participants with whom they interact. The collected data can then be used to populate a sociomatrix which can be subjected to established social network analysis. In principle this approach can be replicated over time to establish how a network changes.

For the sociomatrix to be useful in the context of network disruptions it needs to capture the strength of relationships, direction and any partitioning rules (i.e. networks defined by egos and their roles). In practical terms this may present significant problems in and of itself, but these become amplified when sensitive contextual information is targeted to capture organisational strategy and high dependency relationships in particular. This limitation is further emphasised when a network incorporates competitors and is not constrained to a focal firm.

The limitations (both practical and theoretical) may well be the reason that there are so few pure empirical studies of supply networks.

4.6.2 Empirically Validated Computer Simulations

A feasible means of overcoming some of the restrictions described above for pure empirical studies is that of computer simulation, the validation of which can be anchored in empirical data. Such an approach allows the researcher to at least embrace the philosophical position that CASs are sensitive to initial conditions and perpetually changing. Once a model has been validated against some real world observations of an existing system, experiments can be carried out which vary the initial conditions and indeed potentially some parameterisation of behavioural algorithms. In this way a greater extent of the possible solution space can be explored giving the researcher the opportunity to identify patterns of emergent behaviour that can be linked to the parameterisation of behavioural rules.

Datta and Christopher (2011b) use such a simulation approach to show how decentralised/ centralised planning plays a part in the resilience of a firm’s internal supply chain. The configuration of the model is validated against empirical data before behavioural freedoms are introduced allowing the simulated firm to discover better ways of achieving its objectives. The emergent behaviours and successful strategies can then be compared to real world operations to identify improvement trajectories.

Li et al. (2009) uses empirical data in a slightly different and arguably less robust manor. They develop a computer simulation to develop loose theory and then use a vignette of a case study as an exemplar of the archetype patterns identified in the model. Such an approach relies on the ontological argument that if patterns can be established from theoretically robust behaviours, then real world examples of such patterns must exist and identification of such cases can be used to validate the computer simulation.

Computer simulations augmented by empirical calibration certainly extend the range of explorative research, whilst also being able to anchor the model conceptualisation in real world data. In addition they inherit some of the constraints of the real world which contextually emerged from the unique histories of supply network participants. As such empirically calibrated models can be justified as superior to empirical data in circumstances which dictate the controlled exploration of a large response space and do not necessarily have robust theoretical foundations for simulated firm behaviour.

4.6.3 Using Behaviourally Validated Computer Simulations to Develop Theory

Networks and supply networks in particular, fall into a class of phenomena which in real world terms are boundless and difficult to define/difficult or impossible to collect meaningful descriptive data from. For instance, the participants in a supply network may all have different ways of measuring collaboration, profits, and supplier performance. Furthermore access to all a supply network participants may not be guaranteed or at least be conditional. Whilst it is theoretically possible to impose or derive standardised measurements, the magnitude of this task across many organisations is beyond the scope of this thesis.

In such circumstances Davis et al. (Davis et al., 2009)suggest that:

"[computer] simulation can provide superior insight into complex theoretical relationships among constructs, especially when challenging empirical data limitations exist."

Simulation is a broad description of methods that use computer software to virtually represent 'real world' processes, systems or events (Law and Kelton, 1991), and as such they necessarily incorporate levels of abstraction/simplification (Lave and March, 1975). In order for any simulation-based theoretical contribution to be robust it must be anchored by existing theory, which has led some to question what contribution simulations can make to theory creation/building/development (Chattoe, 1998; Fine and Elsbach, 2000). However, the incorporation of established behavioural models into a single computer simulation controlled appropriately designed experiment can elucidate the dynamic interactions between organisations and processes (Nair and Vidal, 2011; Brintrup, 2010; Datta and Christopher, 2011b; Chang and Harrington, 2000; Li and Sheng, 2011).

Such simulations can build a new level of linking propositions for extant constructs and produce theory which can subsequently be exposed to more easily designed empirical tests. This type of computer simulation also benefits from a need to develop explicit logical arguments as the means by which constructs are linked. This contrasts with the use of empirical observations to support hypotheses without necessarily testing mechanisms of causation. Without the ability to control experiments through extensive parameterisation the emergent theory from traditional empirical research into complex phenomena can become overly restrictive or trivial (Pathak et al., 2007a).

Consequently, the starting point for using simulation as described above has to be weak or underdeveloped theory which has no strong/robust linking propositions, weak logical arguments, and poorly defined boundary conditions.

Validating a model that generates a large range of initial state conditional networks is difficult as only one network can exist in reality. This perceived weakness in the pure computer modelling approach can be overcome by solidly anchoring the behaviour of the network participants in robust theory. By taking this approach the modeller can assure themselves that if the initial conditions assumed had persisted in reality then the agents/firms could have legitimately responded in the manor captured by the model's algorithms.

Given the ontological and epistemological imperatives described earlier (i.e. emergence generated by many autonomous interactions), it is not surprising that the majority of the contributions to date regarding supply networks have been either conceptual or based on computer models.

4.6.4 Summary of Theory Building Approaches Suitable for Supply Networks

Table 4-1 summarises the theory building approaches suitable for networks, along with their advantages and disadvantages.

Table 4-1: Advantages and disadvantages of network theory building approaches

Approach	General description	Advantages	Disadvantages
Empirical real world studies	Collection of real world empirical data to inductively build theory or deductively test existing theory	• Data is robust • Easy to validate	• Difficult to control variables and to carry out experimentation
Computer Simulation	Computer simulation of real world phenomena which uses the real world data for validation	• Data is robust • Easy to validate • Allows the parameterisation of variables and therefore experimentation	• Limited by real world data and access to it
Computer Modelling	Computer simulation that is generalised but draws on strong theoretical anchors for validation	• Allows the parameterisation of variables and therefore experimentation • Not limited by access to real world data	• Cannot be validated against real-world empirical data

The ontological and epistemological imperatives described in the previous section guide this research towards the computer modelling approach, mainly because it is not possible to guarantee access to time related real world empirical data across a boundless network that accepts the exit and entry of firms to and from a system.

4.6.5 Computer Simulation/Modelling Approaches

Computer simulation approaches can be divided into two distinct categories: those that assume processes are continuous and those that are concerned with events and timings that are discreet and punctuate the continuum of time. There is arguably a third type of computer simulation which has generally been labelled as operational research or optimisation, and these approaches are mathematical and deterministic or stochastic and are generally concerned with supporting decisions such as the location of warehouses, level of inventory batch sizing, or inventory management practices.

The following sections describe the various computer modelling/simulation approaches and their application to supply chains/networks.

4.6.5.1 System Dynamics

System dynamics is founded on the pioneering work of Jay Forester (1958) who used computer simulation to show how demand can become amplified as it flows upstream in a supply chain: a retailer batches their orders to a supplier, and the supplier then batches their orders to their supplier, and in so doing the original demand can be shown to oscillate with increasing amplitude and periodicity as it moves up the supply chain.

Forrester (1958) was extremely careful in the specification of his computer model, to quote directly:

> *"To determine the behaviour of a system by simulating the performance of its parts requires that one describe exactly, and in detail, the characteristics which are to be included. The*

validity of the outcome of the system studies depends on the judgment of what is pertinent to include in the system description."

This not only serves to emphasise the importance of correct specification, but also how one of the most significant insights into supply chain operations was developed - not from empirical observations but from computer simulations.

Forrester recognised that the supply chain system was one of continuous flows and control through various feedback mechanisms and his conceptualisation is presented in Figure 4—1.

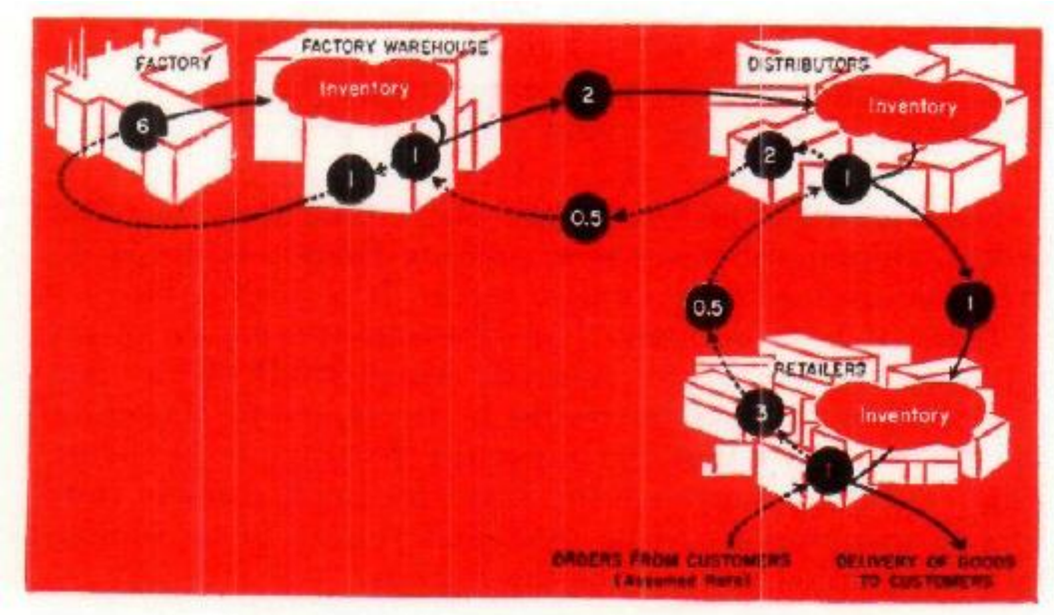


Figure 4—1: Continuous flows and feedback of a supply chain system

Source: Forrester (1958)

This elegant model captures the essence of parsimonious specification: a computer simulation to explore the impact of delays, ordering practices, and inventory management processes on the dynamic response of a system. In so doing Forrester (1958) accepted (at least in his first specification) that effects such as marketing, promotions and competitive action did not need to be considered.

The systems dynamic approach to computer simulation has proved extremely valuable in developing our understanding of many issues related to demand amplification, such as the impact of information sharing, inter-organisational collaboration and inventory management practices. Indeed it secured the central axiom that supply chain management is primarily concerned with: flows of material, information and cash.

Interestingly, Forrester's (1958) first computer models fell into the category of models that were not validated using real world data, and were primarily concerned with developing or extending the simple theory that already existed to describe decisions of how much a firm needs to order and when to place an order. Forrester merely extended this concept across organisational boundaries.

4.6.5.2 Discrete Event Simulation

Discrete event simulation assumes that the phenomenon of interest is not continuous but is captured in specific events. These events may persist in time and at the level of the event may well assume continuous characteristics.

In supply chain simulation terms it is hard to differentiate between discrete events and system dynamics, this is probably because of the fundamental nature of a supply chain which is concerned with the flows of material from one organisation to another. However, there is an established place for discrete events within this continuum, for instance the availability of capacity, disruptions, changes in cost parameters (Rosenfield et al., 1985), and time compression (Chang and Makatsoris, 2001).

The combination of discrete events with system dynamics has proved useful in the understanding of external events (Lee et al., 2002) such as disruptions and catastrophes, and in the timing of decisions such as supplier switching. This combination of approaches comes close to mimicking the real world and is conceptually similar to ABM described later.

4.6.5.3 Optimisation Methods

If simulation is about understanding relationships between variables, there exists another set of computer models that are primarily concerned with optimisation. Whilst these computational methods may seem inappropriate to an ontology where local optimisation is prioritised over system optimisation, the findings of such models are often operationalised heuristically, and it is therefore worth considering them if only to establish computer simulation as a feasible means of establishing supply chain and network theory.

Optimisation approaches can be characterised as having an objective function which can be expressed as the minimisation or maximisation of a dependent variable subject to various constraints. The general form of approaching optimisation problems can be demarked by whether or not the problem can be defined as either mathematically resolvable (linear programming, integer/mixed integer programming and non-linear programming) or only resolvable by searching through a range of potential solutions to find the best (gradient-based, meta-model, statistical and random search/heuristics).

Mathematical optimisation methods have been extensively applied to answering strategic, tactical and operational supply chain problems, such as where to locate warehouses, how to minimise transport costs, and how best to organise picking within a warehouse. The search methods of optimisation have been used to address phenomena where there are a number of interrelated independent variables, such as the establishment of an optimal inventory policy given uncertainty in demand and supply and where demand is modified by availability (Spall, 1998; Zadeh, 1999; Zhao and Melamed, 2009) .

4.6.5.4 Agent Based Modelling

ABM is an organisation of code and processing that allows multitudinous simultaneous actions to take place within a computer simulation. This organisation of code simulates real world social phenomena much more adequately than other code and processing organisations that are more orientated to processing actions sequentially. This facility has been widely adopted in computer simulations of social systems as it allows system behavioural characteristics to emerge and avoids arguments of tautology much more easily than with other computer simulation approaches. It is this aspect of ABM that makes it suitable for exploratory computer simulations of complex phenomena designed to expose emergent relationships between variables.

ABM differs from the other forms of modelling previously mentioned in that the design is focused on individual action which is formatted as a set of simple generic rules that each agent applies using its state variables as inputs, thus giving a general rule a specific interpretation. This contrasts with other forms of simulation which reflect an abstraction of an observed system.

ABM has been commonly applied in the understanding of highly dynamic ecological systems, such as social networks (Gilbert and Doran, 1994), and other time series evolutionary problems including supply network behaviour. In this context ABM simulations have developed some traction in efforts to understand networks that have a scale (population, temporal, geographical or relational) which precludes the collection of empirical data from which to inductively develop theory.

The importance of Choi et al.'s (2001a) conceptualisation of supply networks as CASs becomes clear in the consideration of how research into CASs, and in particular supply networks, can be carried out as they provide the basic structure and components from which a model of a supply network as a CAS can be constructed, thereby adding to the case for the incorporation of autonomous parallel action into any computer simulation.

4.6.6 Verification and Validation

The believability of any theory developed using computerised simulations/modelling is self-evidently a model's verification and validation. Verification provides the assurance that our articulation is not devoid of any aspects we had wished to design into the model. In contrast, validation is the process by which we assure ourselves and others that the model is sufficiently rich to adequately reflect the real world. Normally validation draws heavily upon the gathering of real-world empirical data which can be used to check the outputs of the abstracted model; however, as previously described there are occasions where empirical data is difficult to collect. In such circumstances the researcher can only anchor the behaviours of the model components in theory, and in so doing make the assertion that if the world behaves as theory describes then the computer simulation/model constructed adequately reflects these assumptions.

4.6.7 Summary of Computer Simulation/Modelling Approaches

In accordance with Jay Forrester's advice on the rigorous specification of computer models, cognisant of a gap in the existing knowledge established in the literature review, drawing on the established knowledge in the field and the specific questions posed by the conceptual framework, any computer modelling approach designed to answer the research questions posed will have to include the following: agency, competitive action, adaptation to improve fitness, dynamic relationships in an open systems context

The adaptation process of a firm is its response to its environment, which when given a unique and individual interpretation amounts to agency, inevitably incorporating competitive action, and responses to emergent events (the consequence of the adaptive actions of others and self), which are ultimately reflected in dynamic relationships and death.

Whilst optimisation computer models are not appropriate to understanding the relationships between variables, system dynamics models when combined with discrete events can be configured to reflect the essential characteristics of the phenomenon of interest.

ABM offers the only reasonable alternative to system dynamics, and the functional difference between the two methods is negligible. However, ABM is easier to implement in terms of the CAS ontology as it requires only the rigorous specification of the agent and not the system, which is emergent and self-organising. For the system dynamics approach to complexity to be implementable it often requires aggregation to a level where the autonomy of individual agents is difficult (but not impossible) to manage.

4.7 Generalised Methods for Building Theory using Computer Simulation/Modelling

Davis et al (2009) present a seven stage roadmap for developing theory using computer modelling/simulation. This approach is broadly supported by other protocols (Law, 2006; Banks, 1998) and is comprised of the following elements:

- begin with a research question
- identify simple theory
- choose a simulation approach
- create computational representation
- verify computational representation
- experiment to build novel theory
- validate with empirical data

Accepting the argument presented in the previous sections allows the adoption of the above framework as a template for the research process. Although it should be noted that the research questions have been previously stated, and the simulation approach was justified in the previous section.

4.7.1 Simple Theory

The simple theory has been drawn from the literature on supply chain management, TCE, SET, and competition theory and is summarised in Table 2-1.

Table 4-2: Simple theory drawn from supply chain management literature

Simple theory	**Relating to**	**Exemplar**
Supplier Selection	Supplier selection process	Dempsey,William A.; 2427 Ellram,Lisa M. 1990; 2731 Shin-Chan Ting 2008;}}
	Supplier selection criteria	(Weber et al., 1991; Dickson, 1966)
Inventory Management	Calculation of Safety stock, re-order point, EOQ	(Waters, 2003)
Supply chain collaboration	Antecedents	(Morgan and Hunt,

		1994)
	Information Sharing	
Supply chain risk Management	Purchasing Strategy	(Kraljic, 1983)
	Relationship management	(Datta and Christopher, 2011a; Fisher, 1997)
Profit Motivation	Economics	(Marshall , 1930)
Inertia	Commitment	(Morgan and Hunt, 1994)

This simple theory is used as the basis for the specification of the computer representation which is outlined in the following section.

4.7.2 Computer Representation

In specifying a computer model's requirements it is desirable to synthesise the research questions and the simple theory described above into a set of modelling assumptions:

- Supply networks comprise organisations making autonomous decisions based on limited visibility of the extended community and their restrictive coordination, which at best extends over their own individual supply chain.
- In order to maintain their competitiveness organisations will periodically review alternative configurations of the supply network.
- In order to maintain adequate supply for their anticipated demand organisations will use established inventory management processes to calculate:
    - statistical safety stock
    - EOQ
    - reorder points
- Supply chain collaboration involves sharing demand information with collaborative suppliers.
- Supply chain collaboration requires commitment which increases relationship inertia.

- Supply chain risk management is primarily reflected in our propensity to adopt multiple sourcing strategies, the prioritisation of supplier financial stability, proximity and quality.
- It is the purpose of organisations to act in the interests of their shareholders and to generate profit within the constraints of established rules and regulations.

The following Chapter will describe the fundamental principles of ABM and the considerations that need to be given to the design of such a model, before describing the specification of the model used in this research.

5 Model Specification

ABM is conceptually capable with sufficient understanding of mimicking the real world. However, the constraints of computational power dictate that a trade-off between the sophistication of individual agents and the population size be considered as the more sophisticated the agents become the smaller the population that can be accommodated. Furthermore, the masking effect created by complexity cannot be allowed to obscure the phenomenon of interest.

There are two frameworks for the design of agent based models: ODD (overview, design concepts, and design details) and that described by Miller and Page (2007). The specification of a model based on an established framework is attractive as it serves the purpose of ensuring that experiments are reproducible using different programming languages and model development environments.

The ODD framework can be shown to be an elaboration of the Miller and Page (2007) approach, with both requiring the specification of:

- How agents interact with the world
- Agent objectives and motivations
- Inter agent communication
- Strategies for adaptation
- Agent cognition
- And diversity

However, the ODD framework is more widely used and more tightly specified, and as a consequence it will be adopted in the specification of the computer model in this research. A summary of Grimm et al.'s () modified ODD framework is given in Table 5-1, and will be used as the template for the specification of the research model.

Table 5-1: Modified ODD framework

Major Component	Sub-component	Brief Description
Overview	Purpose	Provides foundation for the model
	Entities, state variables and scales	Specifies what variables will be used/generated and what scales
	Process overview and scheduling	Describes the dynamics of the model and what influence each process exerts on the model
Design Concepts	Basic principles	Principles adopted in describing agent behaviour
	Emergence	How emergence is reflected in the model
	Adaptation	How adaptation is reflected in the model
	Objectives	What objectives drive agent behaviour
	Learning	How adaptation is reflected in the model
	Sensing	How and what agents sense
	Interaction	How agents interact with each other and the environment
	Stochasticity	How stochasticity is used in the model (distributions and justifications)
	Collectives	What agent types are used and how they are differentiated
	Observations	What observations of the model are made and how these relate to the purpose
Details	Initialisation	How are the initial conditions set
	Input data	What input data is required to make the model work
	Sub-Models	What sub-models exist and how are these used by the agents

The detail required by each of the ODD components of the model specification should be sufficient to allow experiment replication without the constraint of modelling language.

5.1 Model Overview

The model overview provides a high level structured description of the model by explaining: its purpose, the nature of the entities and variables, and how the agent’s behaviour is controlled in terms of timing and processes. The following sections will describe each of the model overview components in more detail.

5.1.1 Purpose

The purpose of the model is to address the research questions posed in the previous chapters.

The model structure is summarised in Figure 5—1 and comprises one agent type embedded in a main object. The main object is residence for global functions relating to the environment, the collection and processing of global data, global variables and parameters. The environment and the collections of agents are all defined in the main object.

5.1.2 Entities, State Variables, and Scales

The generic agent object contains the agent functions, variables and states, which combine to define the agent type and the agent specific attributes.

There are three agent types: retailers, wholesalers, and manufacturers, all representing a particular configuration of the generic agent. The retailers consume inventory and can be supplied by either wholesalers or manufacturers. Wholesalers distribute inventory to retailers and purchase inventory from manufacturers. Manufacturers produce inventory and supply wholesalers and retailers. The agent structure is summarised in Figure 5—1

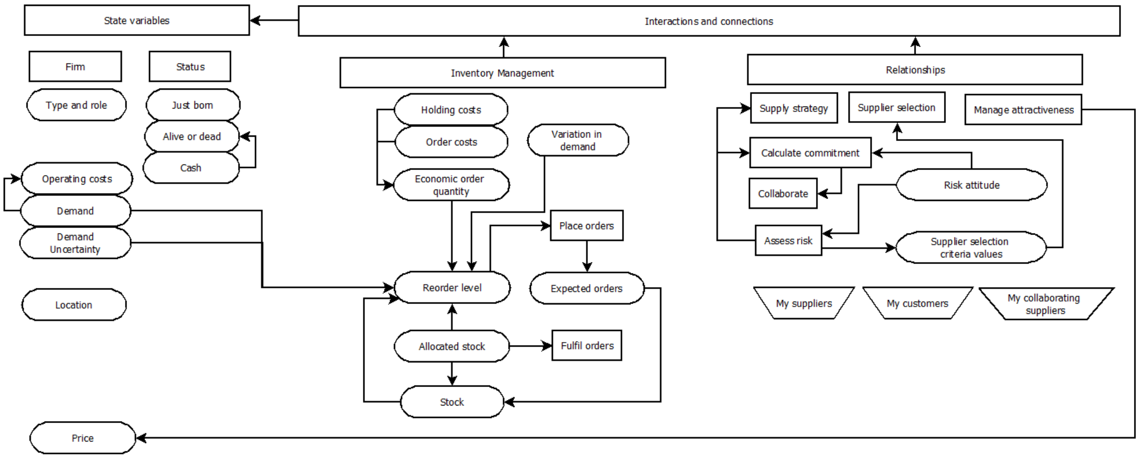


Figure 5—1: Agent structure of the model

Figure 5—1 can be used to highlight a number of state variables that have no intra-agent dependencies or which are used in any intra-agent processes: type and role, just born, alive or dead, location, and cash. The type and role of an agent determines the permissions it has to engage in relationships, for instance a retailer cannot supply any agent, similarly a wholesale cannot supply a manufacturer but a manufacturer can supply any other type of agent.

The just born and dead or alive state variables are used to simplify the programming of the model. Finally, an agent's location is used by buying agents as part of the supplier selection process.

The state variables are summarised in Table 5-2.

Table 5-2: State variables of the model

State Variable	Variable type	Used by [process]	Significance	Scale
Type & role	String	Supplier Selection	Used to identify feasible suppliers	N/A
		Supply Strategy	Used to establish scarcity of supply and dependency	
		Risk Assessment		
Alive or Dead	Integer	Supplier Selection	Only live suppliers can be selected	0/1
Just Born	Integer	Initialisation	To allocate attributes based on the experience of the incumbents	0/1
Operating Costs	Double	Financial Management	Used to calculate fixed costs	0⟶∞
Demand	Double	Inventory Management	Calculate ROL	0⟶∞
Demand uncertainty	Double		Calculate safety stock	0⟶∞
Holding Costs	Double		Calculate EOQ	0⟶∞
Order Costs	Double			0⟶∞
EOQ	Double		Order size	0⟶∞
ROL	Double		When to order	0⟶∞
Expected Stock	Double		Modifies ROL	0⟶∞
Allocated Stock	Double	Inventory Management & Order Fulfilment	Determines stock available to sate orders	0⟶∞
Stock	Double		Used to calculate available stock in the order fulfilment process	0⟶∞
Risk Attitude	Double	Risk Assessment	Modifies global risk	0⟶1
Financial Stability	Double	Supplier selection	Determines which suppliers are selected by prioritising these supplier selection criteria based on context	0⟶1
Flexibility	Double			0⟶1
Quality	Double			0⟶1
Location	Double			X & Y co - ordinates
Price	Double			Range specified in initialisation
Cash	Double			0⟶∞

In the main the scaling of variables is obvious in that those that exist in the range 0 to infinity are describing variables that can assume any positive value. In contrast, the variables describing whether or not an agent is alive or dead, or newly born are binary. However, there are a number of variables describing supplier selection criteria and risk perceptions that are scaled between 0 and 1 which require a more detailed description.

The financial stability of any agent is reflected by the amount of cash an agent has compared to the richest agent of the same type. This ensures that the richest agents are always assessed as having a financial stability of 1 and provides the benchmark for all other agents of the same type.

Flexibility is calculated according to the following formula:

Equation 5-1:

$$Flexibility = \frac{Supplier\ Dependency + Buyer\ Dependency}{2}$$

Where:

Equation 5-2:

$$Supplier\ Dependency = \frac{Buyer\ Demand}{Total\ Demand\ Experienced\ by\ Supplier}$$

Equation 5-3:

$$Buyer\ Dependency = \frac{Total\ Buyer\ Demand}{No.of\ Suppliers}$$

In other words, flexibility is the average of the buyer’s dependency on the supplier and the supplier’s dependency on the buyer. Maximum flexibility therefore occurs when both supplier and buyer totally depend on each other with no alternative buyers or suppliers. It is important to recognise that the buyer’s expectation of flexibility is determined by their perceptions of supply risk, and the full application of these calculations can only be understood in the context of the supplier selection process and algorithm.

Quality is a measure of how many orders an agent has failed to fulfil, and again the value of this state variable is determined by comparing all agents of a type with the agent of that type which has fulfilled the most orders.

5.1.3 Process Overview and Scheduling

Each agent carries out a number of processes which are described in Table 5-3.

Table 5-3: Processes conducted by each agent

Process	Overview	Scheduling
Performance Measurement	Determines status (alive/dead)	Every tick*
Supplier Selection	Determines what relationships an agent forms	Every tick
Inventory Management	Determines when to place orders	Every tick
Calculate Commitment	Determines the appropriate level of commitment based on risk assessment and dependency	Each tick
Risk Management	Determines supply strategy	Every tick
Supply Strategy	Determines whether a dual or single sourcing strategy is required	Every tick
Compete	Determines price based on assessment of capacity utilisation	Every tick
Order Fulfilment	Determines whether or not an order can be satisfied – fulfils order or sends notification that the order will not be fulfilled	When order received

* A tick represents a simulated day

It should be noted that whilst processes such as supplier selection are scheduled for every tick, the likelihood that they will result in a network re-organisation is tempered by the level of relational commitment. That is to say considerations of alternative relationships are shaped by the agent's current relationship in the form of commitment levels, articulated as relational inertia. Inertia develops as a function of two factors: perceived supply risk and mutual dependency. The former is subjective and therefore uniquely perceived by the agent but is based on some assessment of the global supply risk, whilst the latter is a measure of how much both the supplier and buyer are dependent on the other. Where mutual dependency is high neither organisation is incentivised to exit the relationship and the detailed operationalisation of this is specified in section 5.4.5.

The ‘compete’ process refers to the ability of the agent to modify its price in response to how well its capacity is utilised. If an agent’s capacity is underutilised it can modify its prices to make it more attractive to potential buyers (bounded by the conditions of the experiment described in the next chapter). Furthermore, the modification of price is calculated using rolling averages over a 30 day period with a threshold set at an increase or decrease in demand of 20% more or less than capacity, this avoids the agent overreacting to small unstained changes in demand.

In addition to the above agent related process, a number of other processes are executed in the main/global environment and these are detailed in Table 5-4.

Table 5-4: Additional processes executed in the main/global environment

Process	Overview	Scheduling
Create new agents	1 new manufacturer is created every 300 days, 1 new wholesaler every 150 days, and 1 new retailer every 100 days	According to specified timing given in overview
Measure disruption	Measures the number and magnitude of new relationships formed	Every Tick
Determine market share for retailers	Allocates retailer market share according to specified algorithm (detailed in initialisation)	Every Tick
Measure global risk	Measures the coefficient of variation for dependency across the network	Every Tick

Detailed descriptions of the above processes are contained subsequent sections, however some explaining arguments are required for the specification of different birth rates for the different agent roles.

In deciding what birth rates are desirable, it is important to avoid the creation of too many new agents. New agents are created with cash reserves that are consumed by the agent as they evaluate strategies with the purpose of establishing a sustainable business model. In doing so, agents may temporarily distort the market by operating non-sustainable business models. If too many agents are created then the model suffers from permanent distortions.

The birth rate was conceived using the following guiding principles:

- New agents of each type must be created more than twice during the 1000 day simulation run.
- Retailers are created more frequently than wholesalers and manufacturers as they require less investment and are initialised with smaller cash reserves to reflect their lower operating costs.
- Wholesalers are created less frequently than retailers, but more often than manufacturers, thereby reflecting the levels of investment and operating costs.
- New agents are initialised with cash reserves that represent 40 days of the average operating costs for the agent role (manufacturer, wholesaler or retailer). This infers that there should be at least 80 days between new entrant events (as resources would be depleted for unsustainable models by then, giving a reasonable allowance for an unsuccessful business attracting some business).

The next section describes in more detail the model design concepts in accordance with the ODD framework.

5.2 Design Concepts

The purpose of this section is to outline the how the model implements core ABM concepts and follows the established ODD structure/protocol.

5.2.1 Basic Principles

This section outlines the basic principles assumed in the model which are embodied in the processes of: supplier selection, supply risk assessment, collaboration, inventory management, and life and death.

5.2.1.1 Supplier Selection

Each buyer (wholesaler or retailer) selects a number of suppliers based on their single/multiple sourcing strategy determined by their assessment of risk modified by their individual risk attitude. The exact formulation of how the supply risk is calculated is given in section 5.2.1.2.

Suppliers are selected by establishing their viability, do they belong to an appropriate collective (wholesaler or manufacturer), and their utility is determined by the application of relative importance weightings of the behavioural (selection) values, this is described in more detail in section 5.4.2.4 which describes the supplier selection sub-model.

5.2.1.2 Risk Assessment

Risk assessment impacts behaviour in two ways: the adoption of single or multiple sourcing strategies; and the determination of buyer seller commitment and therefore collaboration.

An agent's risk assessment is coloured by their unique risk attitude as applied to a globally defined risk measurement, and in doing so gives each agent a unique interpretation of the network environment. Furthermore, each agent uses their perception of global risk to define their expectations of relational risk, and the specific levels of commitment thereby preferred. The role of risk in agent behaviour is summarised in Figure 5—2.

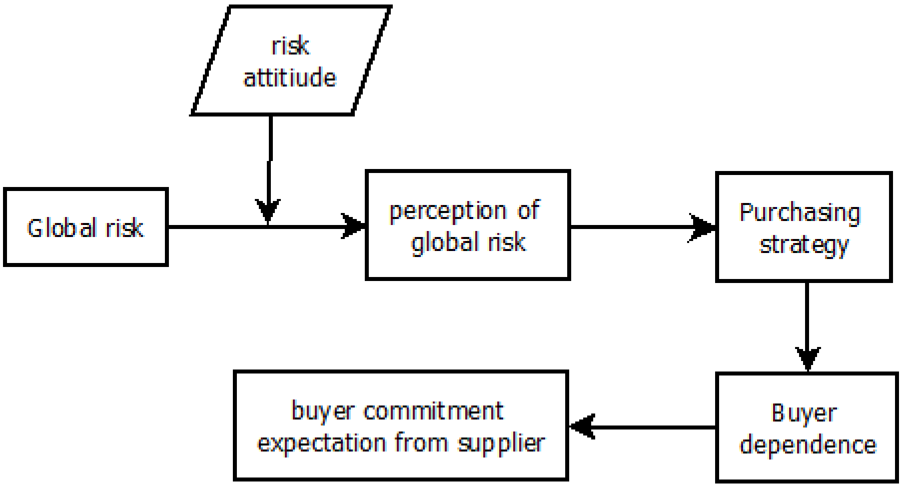


Figure 5—2: Role of risk in agent behaviour

The calculation of global risk uses two calculations of the coefficient of variation (CoV). The CoV is generally accepted as a measure of dispersions and when applied to a network using demand as the variable reveals the variation in dependency across the network. High values denote a higher dependency on a few agents, whereas low values suggest that dependency is more evenly distributed. Essentially, the CoV compares the standard deviation of dependency (expressed as demand) to the average demand. Logically this measurement is only concerned with the demand experienced by suppliers, which in this model's case are represented by wholesalers and manufacturers.

The first calculation yields the maximum theoretical CoV where all supply is sourced from a single entity. This is represented by Equation 5-4.

Equation 5-4:

$$CoV_{Max} = \sqrt{N-1}$$

Where N is the number of supply agents available.

The second calculation reveals the actual CoV for the network, and is calculated using Equation 5-5.

Equation 5-5:

$$CoV_{actual} = \frac{\sigma_{demand}}{\overline{demand}}$$

By comparing the actual to the theoretical maximum, the supply risk of the network is scaled 0 to 1 and this is formalised in Equation 5-6.

Equation 5-6:

$$Supply\ Risk = \frac{CoV_{actual}}{CoV_{Max}}$$

Each actor is given a unique (randomly generated) risk attitude from a normal distribution ranging from 0.2 to 0.8 with a mean of 0.5. The supply risk is then modified by each agent according to the following algorithm:

If $(Supply\ Risk + ((risk\ attitude - 0.5) * Supply\ Risk)) > 1$

$Perceived\ Risk = 1$

If $(Supply\ Risk + ((risk\ attitude - 0.5) * Supply\ Risk)) < 1$

$Perceived\ Risk = 0$

Else

$Perceived\ Risk = (Supply\ Risk + ((risk\ attitude - 0.5) * Supply\ Risk))$

The logic underpinning this algorithm is best explained by considering two agents with different risk attitudes. Agent 1 has a risk attitude of 0.4 (mildly risk averse) whilst Agent 2 has a risk attitude of 0.6 (more risk averse than Agent 1). Now consider a network where the supply risk is 0.5: Agent 1 will perceive the supply risk at 0.45 (slightly less than the actual risk), whilst agent 2 will perceive it as 0.55 (slightly more than the actual risk).

The algorithm is also robust at the extremes, such as when the network risk is high for example 0.8, in this case Agent 1 will perceive the risk as 0.72, and Agent 2 0.88; similarly if the network risk is 0.2 Agent 1 perceives the risk at 0.18 and Agent 2 at 0.22.

Perceptions of risk are used to determine whether or not to single or dual source suppliers; inevitably this modifies buyer dependence which when combined with supplier dependence on the buyer yields the formulation of relational commitment

The operationalisation of risk assessment is detailed in section 5.2.1.2

5.2.1.3 Collaboration and Commitment

The willingness of a supplier to collaborate forms part of the supplier selection process in that if the circumstances dictate that collaboration is desirable then those partners most likely to collaborate are given preference. The degree of flexibility desired of potential partners is calculated according to the following formula:

Equation 5-7:

$$Buyer\ flexibility\ requirement = \frac{1}{No.of\ suppliers}$$

Where the number of suppliers is determined by the supply strategy formed from a firm's perception of supply risk. In circumstances of high supply risk the number of suppliers will be 2, otherwise it will be 1.

Once suppliers have been selected the decision to collaborate or not is determined by three factors: the supply risk, buyer dependency and supplier dependency. The calculation of supply risk has already been given in Equation 5-6.

Buyer dependency is defined as:

Equation 5-8:

$$Buyer\ dependency = \frac{1}{No.of\ suppliers}$$

Supplier dependency is defined as:

Equation 5-9:

$$Supplier\ dependency = \frac{Demand_{buyer}}{Demand_{total}}$$

Relational risk is defined as:

Equation 5-10:

$$Relational\ risk = ABS(Buyer\ Dependency - Supplier\ Dependency)$$

Relationship commitment is defined as:

Equation 5-11:

$$Relationship\ Commitment = \sqrt[3]{Supply\ Risk * Buyer\ Dependency * Supplier\ Dependency}$$

This formulation ensures that relationship commitment does not prioritise any of the input variables and is scaled 0 to 1. It should be noted that all the input variables will be >1 except where the network has assumed a minimal risk configuration resulting in the perfect market requiring no relationship commitment.

If the relationship commitment is >0.5 then the buyer shares demand information with the supplier in real time allowing the supplier to remove any impact that the relationship may have on the bullwhip effect.

The operationalisation of information sharing is captured in the collaboration sub-model described in section 5.4.5.

5.2.1.4 Inventory Management

All agents calculate the amount of safety stock required to protect them against uncertain demand for a given service level. The agents also calculate the EOQ based on assumed holding rates, order costs, their buying price and specified ordering costs. Buying price is determined by the supplier selection process. Finally, each agent will establish an appropriate inventory level at which to place orders based on its selected suppliers and their lead time, which in turn is determined by their location. The operationalisation of inventory management is described in section 5.4.3.

The EOQ is calculated as:

Equation 5-12:

$$EOQ = \sqrt{\frac{2 * Demand * Ordering\ costs}{Holding\ costs}}$$

Where demand is the demand for the year, ordering costs reflect the cost of placing an order and reflect the cost of holding inventory, generally assumed in the model to be 25% of the purchase price.

The re-order point is calculated as:

Equation 5-13:

$$Re - order\ point = Lead\ time * Demand$$

Where lead time is the elapsed number of days between placing and receiving an order.

The safety stock is calculated as:

Equation 5-14:

$$Safety\ stock = 1.65 * \ \sigma_{Demand} * \sqrt{Leadtime}$$

Where 1.65 reflects a 98% availability, σ_{Demand} is the standard variation in demand, and lead time is the elapsed number of days between placing and receiving an order.

5.2.1.5 Life-and-Death

Agents are provided with an amount of cash upon model initialisation or their post-initialisation creation (see section 5.1.3 for details). Regardless of revenue cash is consumed by the agents to satisfy fixed and variable costs. Fixed costs are set at initialisation and represent 80% of the initial sales volume, whiles variable costs are associated with inventory holding and the transport/distribution costs associated with fulfilling orders. No other costs are accounted for in the model.

If an agent exhausts its cash supply (which can be replenished by revenue created through sales) it dies and can no longer partake in the simulation.

New agents are introduced into the environment at a rate determined by the model parameters (previously described and discussed in section 5.1.3). The behavioural variables of these agents is randomised which allows the system to discover new behavioural variable mixes which can challenge the incumbent agents.

5.2.2 Emergence

Each agent executes its processes autonomously as guided by their state variables (see section 5.2 for operationalisation of this behaviour). Conceptually, the autonomous activity of each agent is executed before each time step takes place and effectively represents an environment generator as the aggregated effects are presented to the agents within the time step, thereby providing an environment to which the agents subsequently react. No agent has *a priori* knowledge of any other agent's actions or the consequences of those actions, for instance the aggregated effect of the supplier selection process and the placing of orders may result in some suppliers having no inventory available, and the re-evaluation of pricing strategies as part of the adaptation processes followed by each agent may result in an increased or decreased market share depending on the actions of other agents across the behavioural space.

5.2.3 Adaptation

Agent adaptation within the model takes two forms: adaptation to changes in risk, and competitive adaptation to increase capacity utilisation though the manipulation of price.

As the risk environment changes agents modify their supplier selection criteria and their supply strategy. The influence of perceived risk on supply selection criteria is detailed in section 5.4.2.

Agents monitor their capacity utilisation (capacity is allocated during the initialisation phase and is described in detail in section 5.3.1). If the 30 day rolling average of experienced demand is more than 20% below an agent's capacity, then the agent endeavours to make itself more attractive by reducing its price, and similarly if capacity is over utilised by more than 20% the agent increases its price (within the constraints describing the market conditions for the experiment). By maximising capacity utilisation the agent also maximises its revenue and therefore profit.

5.2.4 Objectives

Each agent has two objectives: to minimise risk and to maximise capacity utilisation.

The pursuit of profit is strongly anchored in the literature summarised in the literature review (TCE and classical economics). Similarly, the intent to minimise supply risk is anchored in the supply strategy literature and has also been previously discussed.

The objectives described above neglect strategic alliances that sacrifice current profit opportunities for greater future profits. This simplifying assumption can be defended by reflecting on the purpose of the model which is to understand whether normal operations generate disruptions. Strategic alliances created to disrupt existing markets by sacrificing immediate financial priorities are, if successful, guaranteed to generate disruption, but do not represent normal operations.

5.2.5 Learning

There is no learning within the model; the agents do not retain knowledge based on their experience of previous adaptations.

5.2.6 Prediction

The only prediction made by the agents is based on the assumption that the immediate past is the best indication of the immediate future. This is primarily reflected in the calculation of safety stock and the timing of orders (this is operationalised in the inventory management sub-model described in section 5.4.3). In a similar fashion, the application of quality criteria in the supplier selection process penalises poor historic performance.

5.2.7 Sensing

All agents sense their environment in terms of their interpretation of dependency patterns which guides the supply strategy. Further sensing takes place at the dyadic relational level with agents sensing the dependency of partners to develop an interpretation of relational risk, which guides relational commitment and the development of relational inertia.

Agents also sense their environment by placing orders with suppliers and monitoring whether or not the supplier agent satisfies that order. Furthermore, all agents can measure the supply populations' performance in satisfying orders. In this way an agent can establish which agents make good partners and which do not.

5.2.8 Interaction

Agents interact directly with each other through the placing of orders and the communication of whether or not there is any stock available to satisfy those orders. Buyers place orders with selected suppliers which are fulfilled providing the supplier has sufficient inventory. If the supplier does not have sufficient inventory the buyer is notified and the performance of the buyer is downgraded to reflect its inability to sate the order, this will be reflected in subsequent supplier selection processes by a depreciated value for quality.

The description of how this is operationalized is given in section 5.4.4

5.2.9 Stochasticity

Stochasticity within the model is generally used to produce noise around normalised behaviour and to apply probability densities to outcomes. Table 5-5 summarises where stochasticity has been used in the model.

Table 5-5: Instances of stochasticity in the model

Variable	Stochastic description	Operationalisation
Location	X and Y coordinate: Uniform (min=0.2; max=0.8;) * 500	Randomly locates agents in a space 500 * 500 (units represent km)
Price	Uniform (min, max)	The minimum and maximum value is specified according to the agent type by the experiment market conditions
Risk Attitude	Normal (min =0.2; max= 0.8; mean = 0.5)	Provides a range of risk attitudes which avoids synchronicity
Current Demand for Retailers	Variation in σ_{demand} drawn from a uniform distribution (min=0.03; max=0.05) Current demand taken from normal distribution (mean as specified, standard deviation as determined from above)	Ensures there is a degree of uncertainty in the retailer demand
Create new agents	Timing is specified with variation added drawn from a uniform distribution (min=1; max=15)	Avoids synchronicity of new agent creation

Consideration of Table 5-5 reveals that two types of distribution have been used in the model: normal and uniform. Normal distributions are generally used where normalising factors are expected, for instance in supplier selection values and stock. Uniform distributions have been used where constrained randomness is expected, for instance location and price. Price is initiated using uniform distributions to give a randomness or variation to the initial conditions; however, it should be noted that price is subsequently modified by the agent with the intent to maximise capacity utilisation.

5.2.10 Collectives

There are three collectives used in the model: retailers, wholesalers and manufacturers. The unique attributes assigned to each of these collectives are summarised in Table 5-6.

Table 5-6: Attributes of the three collectives in the model

Collective	Description	Operationalisation
Retailers	Consume stock	Retailer demand is determined using an algorithm that mimics a pareto distribution dimensioned using price proportion of market share (see Figure 3—2)
Wholesalers	Operate in a price band that is < retailer price but >manufacturer price	They persist in the model where it makes sense for a product to be concentrated at wholesalers in preference to manufacturers.
Manufacturers	Produce product using raw material costs as their main input	The model requires that there is always one manufacturer

5.2.11 Observations

The model provides a rich source of data and the following data is collected from the model when disruptions are detected (Table 5-7):

Table 5-7: Data collected from the model after detection of a disruption

Measurement	Purpose
Experiment version	Records each experiment
Replication	Identifies the replication
Time	Records the time of the event
Manufacturing Price Variation	Records the experiment settings for market structure
Retail Price Variation	
Wholesale Price Variation	
Wholesale Margin Input	
Buyer	Records the buyer in the relationship
Supplier	Records the supplier in the relationship
Magnitude of Change	The magnitude of change as expressed in the number of units normally exchanged in the relationship
Total Number of Connections	Used to describe the connectivity and nature of the network
Total Magnitude of Connections	
Number of Live Retailers	
Number of Live Wholesalers	
Number of Live Manufacturers	

These observations allow an analysis that assumes a supply network behaves as a CAS, which is critically organised generating a long tailed cumulative distribution of events described by frequency and magnitude. The data also facilitates other analysis regarding the temporal separation of events.

5.3 Detail

5.3.1 Initialisation

The model is initialised by reading the input data describing the overall retail market size expressed as units, the number of retailers, the number of wholesalers, and the number of manufacturers. The algorithms summarised in Table 5-8 are then applied to the input data.

Table 5-8: Initialisation algorithms

Algorithm	Purpose
Read input file	Provides market and population data
Give location to agents	Random locations provided to control (through repetition) for location within the experiments
Determine selling price for all agents	To provide initial value to determine current attractiveness reflecting a unique history for each agent
Allocate demand to retailers based on pricing strategy	Retailers provide the pull in the system and their selection of suppliers combined with their demand determines the systems dependency
Allocate demand to suppliers based on initial supplier selection criteria	Having allocated demand to retailers the demand is distributed across the supplier agents through the supplier selection process
Allocate stock to all agents based on buyers selections	Every agent is allocated 100,000 units of stock
Allocate capacity to each agent based on their initial demand	Each agent’s capacity range is set at their initial demand +/- 20%

The initialisation process ascribes each agent with feasible variables that reflect a unique history allowing new structures of relationships to emerge based on the micro-macro interactions described previously, specifically:

- Each agent is given a location randomly generated using the distribution previously described.
- Each agent is assigned to a collective or type (i.e. retailer, wholesaler or manufacturer).
- Each agent is given an amount of initial stock (100,000 units). As each agent consumes this stock at different rates the amount of stock can be the same for each agent and there will be no synchronicity of ordering as a consequence.
- Each agent is assigned a selling price according to the market conditions described by the experiment parameters, taking account of which collective they belong to.

The initialisation makes two important assumptions: location is random and does not follow any pattern; and retailer attractiveness is determined by price.

The first of these assumptions is justified by considering an alternative assumption that suppliers will cluster around buyers. This is accounted for in the model through the life and death process: suppliers that are not attractive will not survive and new entrants that are more attractive because of their location will displace less attractive incumbents.

Wholesalers and manufacturers measure their demand directly from the orders they receive. However, the model does not have any customers for retailers and assumes that market share follows a Pareto distribution implemented using the following algorithm:

1. Sort all retailers in reverse order of selling price
2. Staring with the agent with the lowest selling price
    a. Allocate 20% of the market
    b. Reduce the market by the amount just allocated
3. Repeat until the market is reduced to less than 0.1 (note 0 is never achieved using this algorithm)

Having allocated the retailers' market share, the retailers then choose suppliers based on price alone. It should be noted that this selection is temporary as the selection criteria will be subsequently modified when data has been generated to reflect each supplier's additional selection criteria of quality, location, financial stability and flexibility (these criteria are discussed in more detail in section 5.4.2 describing the supplier selection sub-model).

The above process necessitates the model having a stabilising period of approximately 60 days.

5.4 Sub-Models

The following sections describe the sub-models incorporated into the model and which are used by the agents to implement their 'normal' operations.

5.4.1 Adaptation Sub-Model

Each agent calls this sub-model each tick. Each agent adapts to their interpretation of their environment in two ways: they act to mitigate supply risk, and then to maximise the utilisation of their capacity. The former relies on the following algorithm used to assess supply risk:

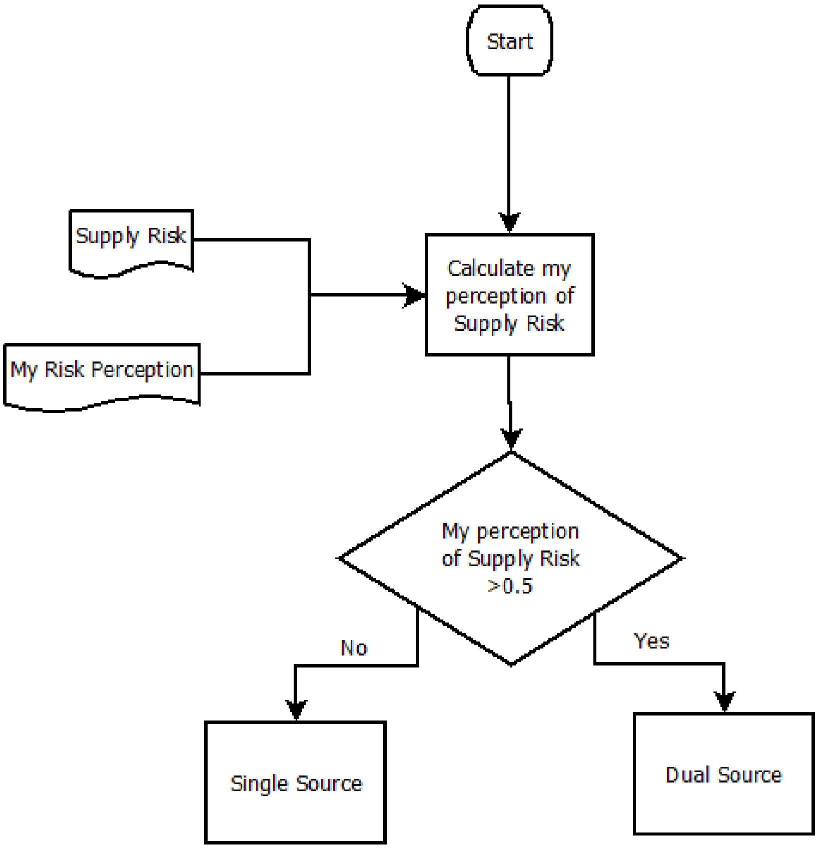


Figure 5—3: Assessment of supply risk algorithm

Each agent then applies a coefficient to the calculated supply risk (calculated as per Equation 5-6) which is a reflection of their risk attitude. This is necessary to: 1) reflect the real world where interpretations are not uniform; and 2) to avoid synchronised uniform adjustments to supply strategy and the supplier selection preference weightings.

The use of dependency as a measure of supply risk is supported in the supply strategy literature previously described (Marshall , 1930; Kraljic, 1983; Williamson, 1993b).

The rationale underpinning the use of price as the primary means of maximising capacity utilisation is again supported in the previously described literature (Marshall , 1930); however, in order to avoid large changes which are both unrealistic and could represent over-reaction, the changes to price are constrained to movements of 10% and the assumed market structure which sets upper and lower bounds for each agent type.

The algorithm used for the maximisation of capacity utilisation is summarised in the flowchart given in Figure 5—4

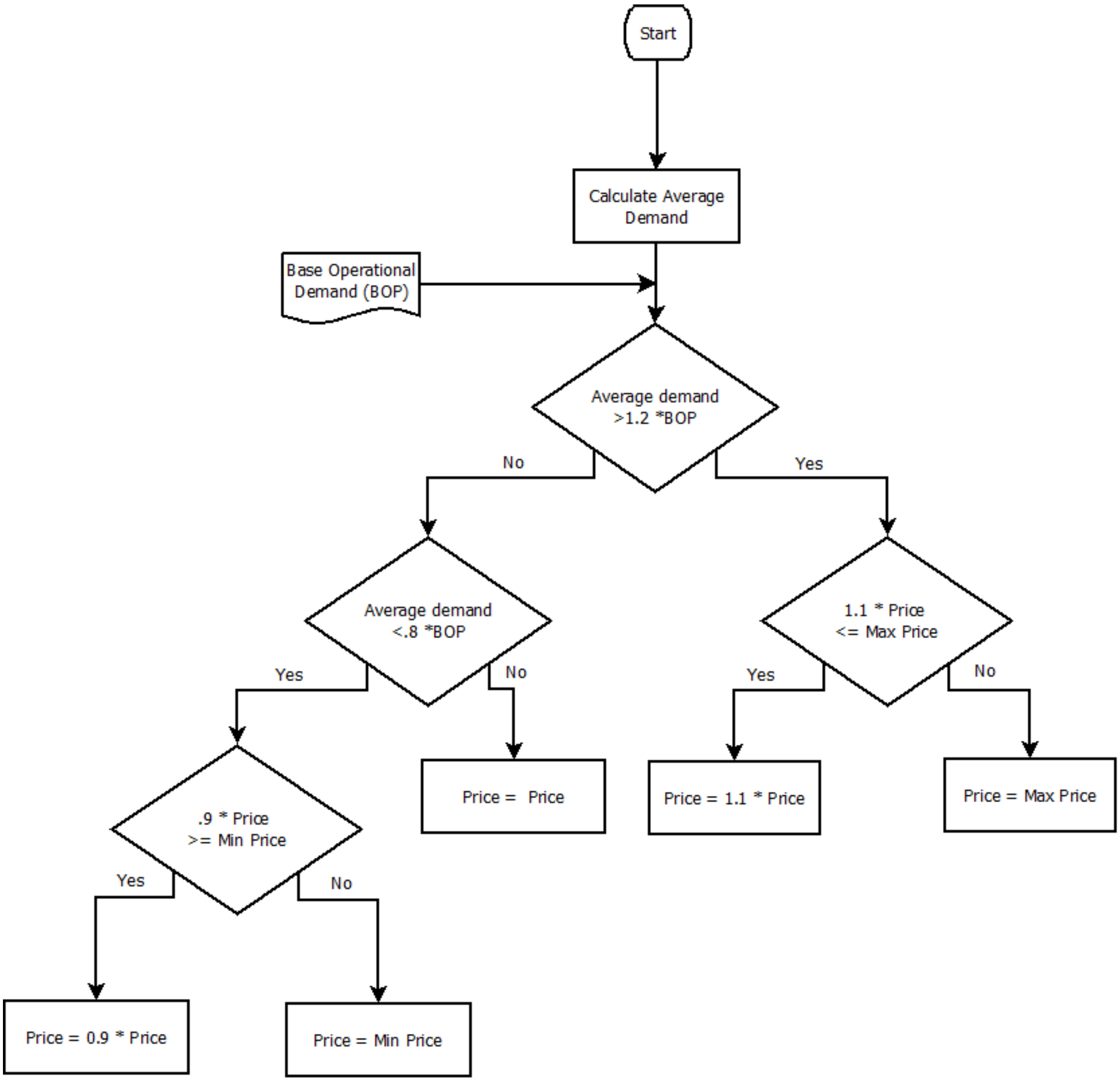


Figure 5—4: Maximisation of capacity utilisation algorithm

5.4.2 Supplier Selection Sub-Model

The supplier selection model exists within each agent and is called at each tick. The supplier selection processes follow a 3 step process: 1) calculate the importance of each of the criteria; 2) calculate the fit of each supplier to each criterion; and 3) calculate an overall score for each supplier.

5.4.2.1 Calculation of Importance Weights

All importance weights are calculated in a way that positions the weighting on a scale of 0 to 1. The importance weighting is an expression of the relative importance of each criterion and is based on a calculated value of the criterion compared to the sum of all criteria values.

The calculated value of supplier financial security is calculated as being equal to the buyer's perceived supply risk (which exists on a scale 0-1). In other words, the highest weight is attached to the financial security weight when the perceived supply risk is greatest. This is formally stated in Equation 5-15.

Equation 5-15:

$$Value\ of\ supplier\ financial\ security_i = perceived\ risk_i$$

The calculated value of location is dependent on the variability of supply (). The closer suppliers, the less the lead time and the less inventory is needed to buffer against uncertainty. Consequently, the value of location is calculated according to Equation 5-16.

Equation 5-16:

$$Value\ of\ location_i = \frac{\sigma_{demand_i}}{\sigma_{demand_{max}}}$$

This ensures that the agent experiencing the greatest uncertainty in demand will place the highest value on location.

The calculated value of price is determined by the agent's consideration of selling margins. Agents with high margins place less emphasis on buying price than those with very low margins. The value of buying price is calculated as:

Equation 5-17:

$$Value\ \ of\ buying\ price_i = 1 - \frac{Selling\ Margin_i}{Selling\ Margin_{max}}$$

Where i identifies the buying agent.

This ensures that the agent with the highest selling margin assigns the lowest importance to buying price.

The calculated value of quality is dependent on the agent's experience of supply and perceptions of supply risk. The importance weight of quality is calculated according to Equation 5-18 and Equation 5-19.

Equation 5-18:

$$Value\ of\ quality_i = \frac{(1 - \%\ orders\ satisfied_i) + perceived\ risk_i}{2}$$

Equation 5-19:

$$Quality\ Experience = 1 - \frac{no\ of\ orders\ satisfied}{no\ of\ orders\ placed}$$

This ensures that the agents which experience the poorest quality place the highest value on quality.

The value placed on flexibility is a reflection of dependency, which in the case of the buying organisation is dependent on the number of suppliers selected in the supply strategy. The value placed on flexibility is therefore formally stated in Equation 5-20.

Equation 5-20:

$$Value\ Placed\ on\ flexibility_i = \frac{1}{No\ of\ suppliers\ selected_i}$$

5.4.2.2 Calculation of Scores

Having established the importance of each criterion based on an agent's context, relative importance weightings can be calculated for each criterion based on the generalised formula given in Equation 5-21.

Equation 5-21:

$$Importance\ weighting_i = \frac{Importance\ Value_i}{\sum_{i=1\ to\ n} Importance\ Value_i}$$

Each supplier's performance against each criterion can then be assessed. Each supplier's performance is compared to the best performance for that criterion using the generalised formula given in Equation 5-22.

Equation 5-22:

$$Relative\ Performance_{i,j} = \frac{Performance_{i,j}}{Performance_{Max,j}}$$

Where i refers to the agent's identity and j to the supplier selection criterion being considered.

The best performance of each criterion is determined using the rules summarised in Table 5-9.

Table 5-9: Rules for selecting the best performance of criteria

Criterion	Best performance
Price	Lowest price
Quality	Highest percentage of satisfied orders
Location	Closest to buying agent
Flexibility	Closest to commitment requirement
Financial security	Highest cash reserves

The total score for each supplier can then be calculated using the formula described in Equation 5-23.

Equation 5-23:

$$Score_i = \sum_{j=1}^{j=5} (Criteria\ Value_j * Performance_{i,j})$$

Where i identifies the agent and j the supplier selection criteria. Equation 5-23 allows suppliers to be ranked in terms of attractiveness, and consequently the most preferable supplier can be identified and selected.

5.4.2.3 Consideration of Commitment

The model assumes that if as previously described the relationship commitment is greater than 0.5, then the relationship partners will collaborate. The collaboration process requires relationship investment in the form of commitment to share information and information sharing process configuration. As described in Chapter 3, this builds relational inertia in the form of a reduced propensity to exit the relationship ().

Each agent maintains a record of suppliers with whom it collaborates. These suppliers receive a premium to their score in the form of a 5% uplift. This ensures that they are the preference as long as they are within 5% of the best supplier.

The collaboration sub-model is described in more detail in section 5.4.5.

5.4.2.4 Summary of the Supplier Selection Sub-Model

The supplier selection sub-model is summarised Figure 5—5.

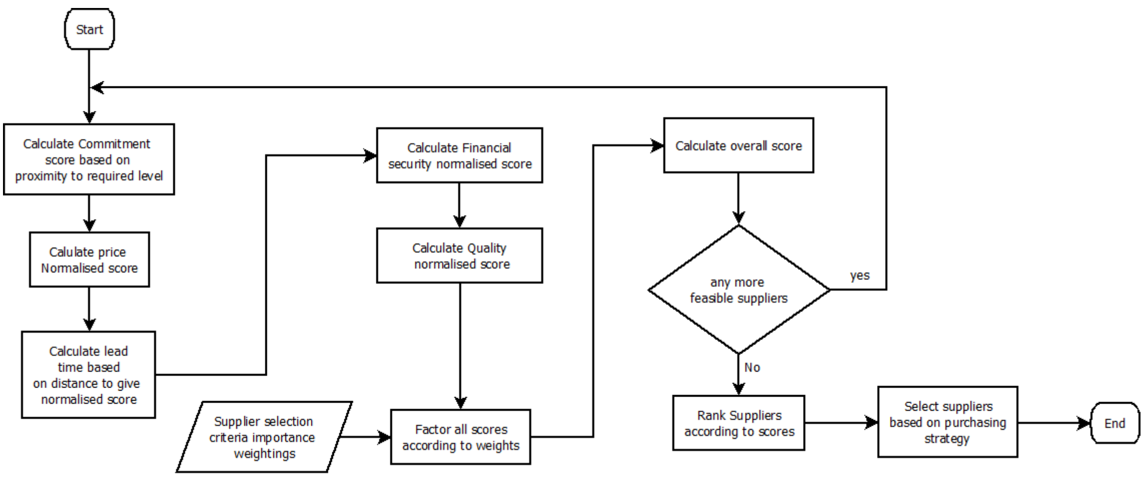


Figure 5—5: Supplier selection sub-model algorithm

In essence, the supplier selection process involves establishing normalised scores for each potential supplier based on their price, commitment, location and financial stability. These scores are then multiplied by the importance weightings given to each of these criteria by the buying agent to yield a weighted significance specific to the buying organisation and cognisant of its priorities. Suppliers can then be ranked according to their overall score and selected according to the purchasing strategy adopted which is a function of an agent's perception of supply risk.

Table 5-10 summarises the specifications of the supplier selection sub-model.

Table 5-10: Specifications of the supplier selection sub-model

Parameters	Selection criteria weightings, supplier prices, agent location, cash position of suppliers
Dimensions	N/A
Design	See Figure 5—5
Justification	Select suppliers that offer the best fit to suppliers selection criteria of the buying agents
Testing (verification)	Comparison with manual calculation
Testing (validation)	Literature
Values	N/A

5.4.3 Inventory Management Sub-Model

The inventory management sub-model requires three agent specific calculations: the reordering point, the EOQ, and the level of safety stock. These are formalised in Equation 5-12, Equation 5-13Equation 5-14 (previously given in section 5.2.1.4)

The safety stock calculation requires each agent to maintain a record of the orders it receives (demand). To avoid over sensitivity the demand used to calculate safety stock is the rolling 30 day average.

Equally, these calculations require the buying organisation to have a reasonable anticipation of the lead times from their selected or preferred suppliers. This is generated using Equation 5-24.

Equation 5-24:

$$Lead\ time_{ij} = Int(2 + \left(\frac{distance_{ij}/_{50}}{24}\right))$$

This formula reflects a day to process the order at each end of the supply, and assumes a transport speed of 50km/hr. The lead time is expressed as whole days.

At each time tick the buying agent assesses its inventory levels together with any expected deliveries (for orders placed and not yet fulfilled) against the calculated reorder level, thereby enabling it to make a decision of whether to place orders with suppliers or not. In the event that a buyer places an order for an EOQ, the buying agent will check that the order quantity is greater than the product lead time and demand. If the EOQ is too small the agent will place more orders until a sufficient pipeline of expected orders is generated. This step ensures that the order quantities are sufficient given a particular anticipation of demand and lead time.

When an order is placed the order quantity is added to the expected order value of the buying agent.

The inventory management sub-model is summarised in Figure 5—6.

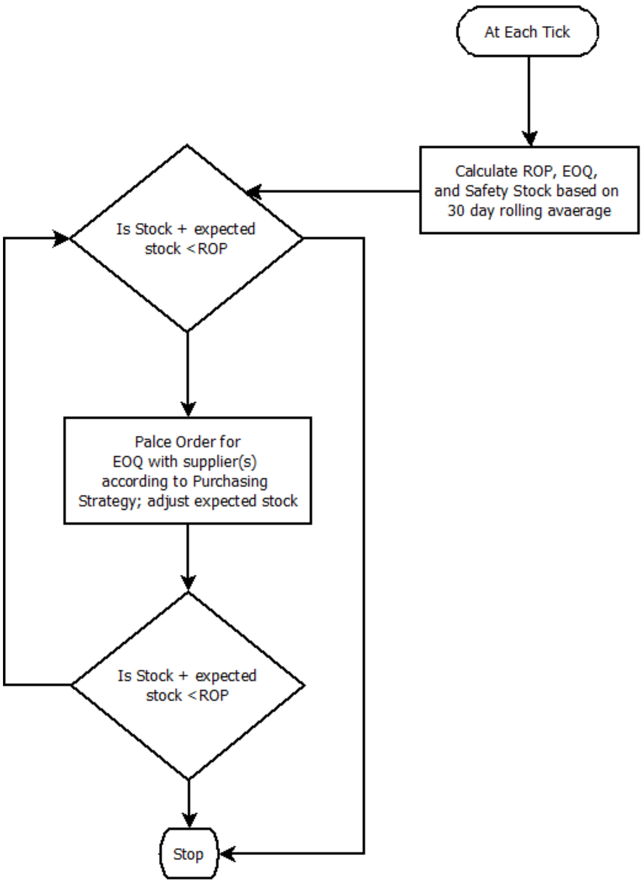


Figure 5—6: Inventory management sub-model algorithm

Table 5-11 summarises the specification of the Inventory management sub-model.

Table 5-11: Specifications of the inventory management sub-model

Parameters	Historic demand, lead time, ordering costs, holding rate
Dimensions	Inventory (units)
Design	See Figure 5—6
Justification	Established processes that are embedded in many real world inventory management systems
Testing (verification)	Compare to manual calculations; test in isolation to establish appropriate inventory management given limitless supply
Testing (validation)	Literature
Values	0 to + infinity

5.4.4 Order Fulfilment

Orders are transmitted in the model as messages detailing the quantity, ordering agent, and lead time.

Upon receipt of an order the agent checks if it has sufficient inventory available to satisfy the order. If sufficient inventory is available then the demand is recorded and two sets of actions are generated:

1. Inventory is moved from the supplier’s available stock to allocated stock
2. An action to move the inventory from the supplier’s allocated stock to the inventory of the buying organisation after an elapsed period specified by the lead time. At the same time the allocated stock of the supplier is downgraded by the appropriate demand and the expected order quantity of the buying agent is downgraded by the order amount

If the supply agent does not have sufficient inventory available it records the order as unfulfilled and sends a message to the buying agent detailing the order quantity and the identity of the supply agent. The buying agent downgrades its expected order quantity by the order amount.

The information collected during the order fulfilment process enables the supply agent to maintain a quality record of how many orders it has satisfied and how many it failed to satisfy

The order fulfilment process is summarised in Figure 5—7.

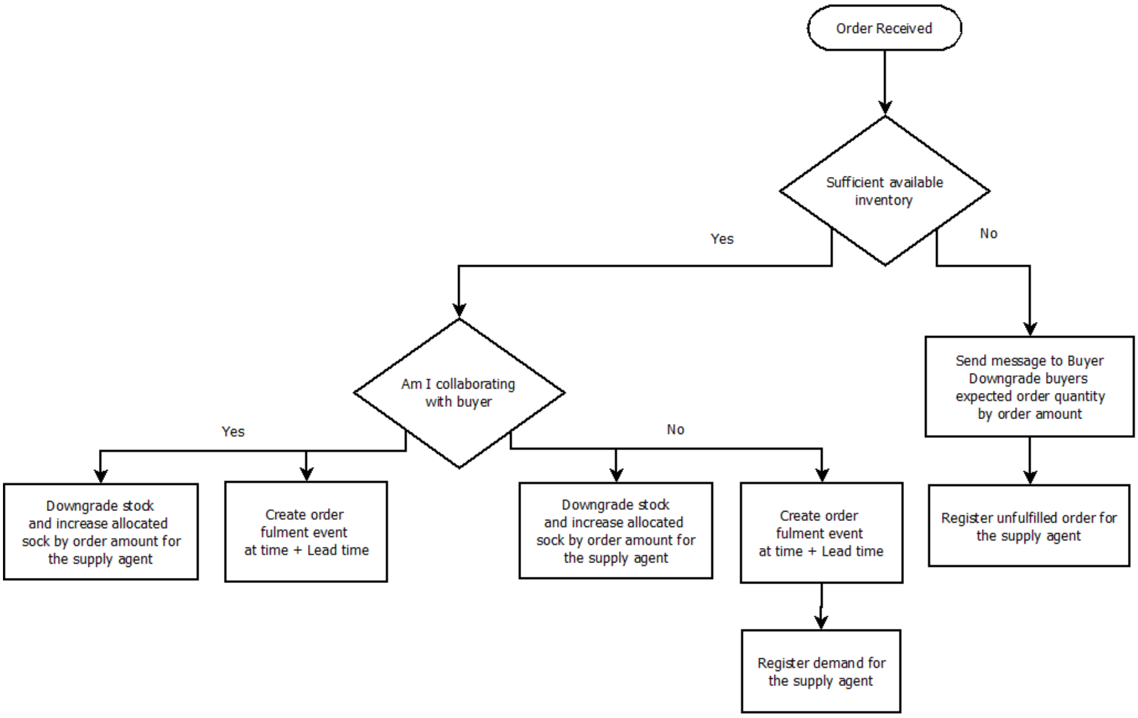


Figure 5—7: Order fulfilment sub-model algorithm

Error! Reference source not found. summarises the specification of the order ulfilment sub-model.

Table 5-12: Specifications of the order fulfilment sub-model

Parameters	Stock, available stock, expected stock
Dimensions	Inventory (units)
Design	See Figure 5—7
Justification	Established processes that are embedded in many real world inventory management systems
Testing (verification)	Compare to manual calculations; test in isolation to establish appropriate inventory management given limitless supply
Testing (validation)	Literature and expert panel
Values	0 - infinity

5.4.5 Collaboration Sub-Model

The collaboration sub-model allows the buying agent to share with its suppliers, on a daily basis, the 30 day moving average demand information providing both organisations having appropriate levels of commitment. This avoids any blurring of the demand signal through order batching by sharpening the demand signal resulting in a decreased level of safety stock. The benefits of the cost reduction achieved by the supplier are reflected in the potential of the supplier discounting its prices to its buying community.

To avoid double counting demand supply agents check whether any received orders are from buyers with whom they are collaborating.

As previously mentioned collaborating suppliers benefit from a 5% uplift in their supplier score in the supplier selection process.

Figure 5—8 summarises the collaboration process.

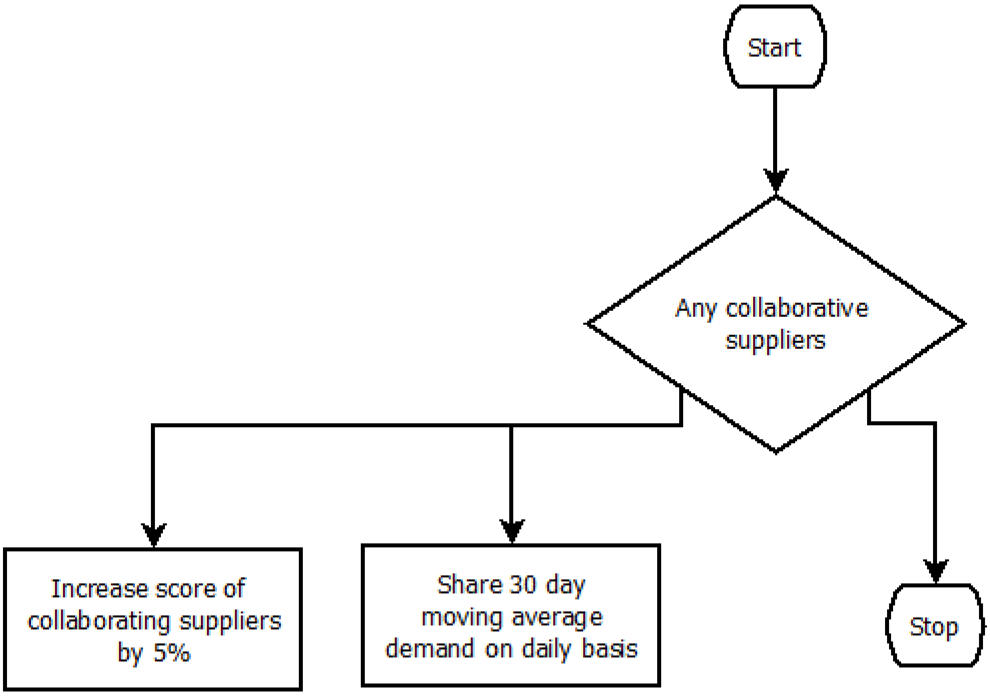


Figure 5—8: Collaboration sub-model algorithm

Table 5-13 summarises the specification of the collaboration sub-model.

Table 5-13: Specifications of the collaboration sub-model

Parameters	Global risk, relational risk, closeness
Dimensions	0,1
Design	See Figure 5—8
Justification	Collaboration is motivated by risk mitigation
Testing (verification)	Generate response curve for a range of parameterised inputs
Testing (validation)	Literature
Values	-infinity to + infinity

5.4.6 Purchasing Strategy Sub-Model

The purchasing strategy sub-model is used by the buying agent to determine its purchasing strategy in terms of whether it has a single or dual source supply. The decision to dual source is determined by the buying agent's perception of supply and risk, which is calculated by comparing the actual supply network configuration with the highest risk supply network configuration. This calculation was given in equation 5-6, although it should be noted that the agent's perception of risk modifies this value as described in section 5.2.1.2.

The model assumes that if the perceived risk is more than half the maximum risk then the agent will dual source.

Table 5-14: Specifications of the purchasing strategy sub-model

Parameters	Supply risk, risk attitude
Dimensions	0,1
Design	See description
Justification	Highest risk is where all orders are placed with a single supplier.
Testing (verification)	Extremes modelled, low variations in dependency result in global risk approaching 0, high variation approach 1
Testing (validation)	Literature
	Expert panel
Values	1 or 2 suppliers

5.4.7 Birth and Death

Agents within the model are initialised with a substantial cash holding; however, when an agent exhausts its cash supply it ceases to exist. This simple algorithm is a significant component of the self-organising process. In a similar vein the model also allows new entrants into the market as they play a significant role in challenging the incumbents and any established norms.

Birth rates have been previously specified and discussed in section 5.1.3.

5.5 Validation and Verification

In the context of computer simulations/models verification refers to the internal consistency that determines model behaviour, whilst validation refers to how well the model/sub-models and algorithms reflect the real world (Campbell and Stanley, 1966).

5.5.1 Verification

Computer models offer high degrees of internal verification as each algorithm can be tested with sample data that should produce known outcomes. To this purpose the algorithms previously specified have been subjected to sample inputs to outputs which were compared to outputs calculated manually. However, whilst this process verifies the individual algorithms it does not verify the impact of integrating the algorithms in a sequence of actions.

A reasonable approach to verifying the integration of algorithms in the model is to build the program (a collection of connect algorithms) incrementally and test at each level of the integration. In principle, this allows the developer to establish whether or not the latest level of integration results in the model performing as anticipated; however, as the complexity of the program develops it becomes increasingly difficult to predict model outcomes.

An alternative approach to verifying a model with high levels of integration involves the use of placing breakpoints within the program that allow variables to be traced at each time step. Changes to variables can then be linked to components of the program and specific lines of code.

Once the model designer is satisfied with the program following testing in a simple environment (the smallest number of agents required to allow execution of the programme/algorithm), complexity can be introduced into the model environment by increasing the number of agents.

Table 5-15 summarises the model algorithms and the principles adopted in verifying them, placing them in the sequence of model build.

Table 5-15: Verification of the model algorithms

Sequence of build	Model description	Sub-Model	Test
1	Agents that consume stock	Inventory Management	Check agents stock depletes according to their demand
2	1 + Agents that place orders		Check: 1) agents generate orders at appropriate levels; 2) don't run out of stock
3	2 + Agents that receive orders		Check: 1) agents satisfy orders only when they can; 2) register demand; 3) make the necessary adjustments to their stock records (available, allocated and expected stock)
4	3 +Order fulfilment	Order fulfilment	Check: 1) agents only fulfil orders they have stock for; 2) inventory adjustments are made correctly for both the buying and supplying agents
5	4 + Agents assess risk and develop purchasing strategy	Supply Strategy	Check: 1) globally assessed risk does not exceed 1; 2) risk increases as the number of suppliers is reduced; 3) purchasing strategy changes from single to dual source when perceived risk exceeds 0.5
6	5 + Agents select suppliers	Supplier selection	Check: 1) suppliers are accurately ranked (manual calculation comparison); 2) selected suppliers are registered properly; 3) suppliers are switched when preference is changed
7	6 + Agents choose to collaborate	Collaboration	Check: 1) when conditions for collaboration are met suppliers are registered as collaborating,2) suppliers are removed from the collaboration list when conditions for collaboration are no longer met
8	7 + Agents share demand information		Check: 1) buying agents demand is registered with collaborating suppliers; 2) information is not shared when conditions of collaboration are not met; 3) orders from collaborating partners are not registered by suppliers
9	8+ Agents build relational inertia		Check: 1) collaborating suppliers are given 5% uplift in their scores; 2) suppliers are not given any uplift in their scores when they no longer collaborate
10	9 + Agents modify prices in response to capacity over/under utilisation	Adaptation	Check: 1) agents modify their prices by +/-10% when under/over utilised capacity is >20%; 2) Check prices do not get modified to levels that are outside those permitted by market conditions
11	10 + New agents created	Birth and Death	Check: 1) new agents are created according to specified timings; 2) agents with <0 cash die; 3) new agents are initialised appropriately (initial values)
12	11 + Agents die		

5.5.2 Validation

Verification of complex systems models is certainly difficult (Pathak et al., 2007a; Pathak et al., 2007b; Davis et al., 2007; Pathak et al., 2010). The main problem being that any valid model is nondeterministic and emergent, inferring that small changes in some variables may produce disproportionate changes in outcomes. Verification is further complicated by the difficulty of gathering real-world empirical data against which the system can be compared. This is particularly true of systems such as supply networks that are of large-scale and geographical spread bound together by autonomous decisions made under conditions of bounded rationality.

This thesis uses two approaches to validating the computer model:

- Sound theoretical anchors for the algorithms
- Verification of algorithm descriptions using an expert panel.

5.5.2.1 Theoretical Anchors

Table 5-16 summarises the theoretical anchors for each element of the model described previously in this chapter.

Table 5-16: Theoretical anchors for each element of the model

Sub-model / Core Component	**Algorithm**	**Theoretical anchor**
Core component	Supply risk	TCE: (Kraljic, 1983; Williamson, 1996)
Collaboration	Relational risk	SET: (Hunt and Morgan, 1994)
	Information sharing	Supply chain management: (Fisher, 1997)
Price Competition	Price adaptation	Economics: (Marshall , 1930; Williamson, 1996)
Purchasing Strategy	Single/dual sourcing	TCE, purchasing (Kraljic, 1983)
Inventory Management	Inventory management	Operational research: (Waters, 2003)
Birth and Death	New entrants	CAS: (Bak, 1999)
Supplier Selection	Supplier selection criteria	Supplier selection : (Weber et al., 1991; Dempsey, 1978; Dickson, 1966)
	Relational inertia	SET (Hunt and Morgan, 1994)

5.5.2.2 Panel Verification

In addition to the theoretical anchors provided above, the model was validated at a number of workshops comprising practitioners and academics from the field. The selection of the panel was designed to balance academics with practitioners. The composition of the panel is given in Table 5-17

Table 5-17: Composition of the validation workshop panel

Panel Member	Background	Title and affiliation
Colin Dulson	Practitioner	Supply Chain Director, AAH Pharmaceutical
Mike Griffiths	Academic	Department of Informatics, Shrivenham
Professor Peter Allen	Academic	Director Complex Systems Group, Cranfield University
XX	Practitioner	World Wide Duty Free
Richard Street	Practitioner	Supply Chain Director, Mothercare

In addition to the workshops the approach was presented at the Logistics Research Network conference and the European Operations Management Association conference.

The workshops consisted of the author presenting the algorithms described previously and inviting the audience to challenge the algorithms and the underpinning assumptions.

A number of challenges were presented, and these are summarised in Table 5-18 together with the conclusion reached by the author and the conclusion justification.

Table 5-18: Challenges to the model arising from the validation workshops

Challenge	Response	Justification
EOQ sensitive to holding costs and re-order costs	Agent checks that EOQ covers lead time demand	This amounts to a hybrid approach incorporating elements of both EOQ and order up to levels
Use of a single product does not reflect the complicated nature of real supply chains	The single product abstraction involves less assumptions regarding interdependencies between different products in different organisations which would only obscure the system response and response mechanisms	Single product adopted, but observation noted and reflected in recommendations for further work
Risk assessment is less formalised	This is probably true but it was agreed that it would include the principles of the proposed algorithm	Retain the calculations of risk proposed but note comments and include in recommendations for further work
Supplier selection not as sophisticated as the model		
Births of new companies involves an assessment of the market	Undoubtedly true but the operationalisation of this within the model would introduce added complication	It was agreed that market assessments are typically based on bounded rationality and are often naïve
Responses to underutilisation are more varied than price adjustments	This is also true, but suggestions include activities anticipated in the model such as bundling and strategic location	The single product abstraction does not permit bundling and re-location of resources would require extension of the model run time to beyond reasonable limits within the broad range of experiments necessary
Product criticality ignored	This is also true but the assumption of using a single product requires the strategic purchasing options to be reduced to whether or not to collaborate, and whether or not to dual source	Whilst the implications of ignoring product criticality are clearly a simplification of Kraljic's (1983) purchasing strategy they are supported by TCE, SET and indeed to a large extent by Kraljic
Why not allow multiple sourcing to be more than two suppliers	Extending the possibility of multiple sourcing including more than 2 suppliers would require agents to balance the benefit with the resources and costs required to manage the extra suppliers	Two suppliers was felt to be realistic if not all embracing

5.6 Summary

This chapter has described in detail how the underpinning conceptualisation of supply networks as CASs susceptible to normal accidents as described by NAT has been incorporated into the design of an ABM suitable for assimilation in an experimental design to provide answers to the research questions identified by the literature review.

The model design has been verified at elemental levels through careful stepwise construction, staged testing of components, and integration of components. The algorithms, sub-models and consequently the model itself have been validated by anchoring the design in strong theoretical anchors drawn from SET, TCE, and supply chain management. Further validation was secured through the reflections of an expert panel on the components of the model.

The model was developed using Java programming language in the Anylogic 6 development environment. The model code is provided in Appendix A

The next chapter will describe the design of the experiments used to generate data from which the answers to the research questions can be developed through appropriate analysis congruent with the theoretical underpinnings of CAS and NAT.

6 Experiment Design

Chapter 4 showed how the collection of real-world empirical data using survey methods whilst notionally attractive has practical limitations when trying to understand a complex system's behaviour in response to events that are unpredictable and often rare. Furthermore, the difficulty in establishing real-world systems boundaries is prohibitively resource expensive.

Chapter 4 also showed how computer models can be built using established supply chain practice as the basis for organisational behaviour. Although the model abstraction is founded on empirically validated organisational behaviours it extends the environment within which these behaviours play out, thereby providing a more realistic representation of the real world than that which would be deliverable from even the highest quality surveys.

Chapter 5 specified a computer model that is anchored in extant theory, but which accepts a new dynamic environment. Furthermore, the model specification, cognisant of the research questions identified in Chapters 2 and 3, provides the basis for submitting the model to a series of experiments designed to answer the research questions. As a consequence, this chapter is primarily concerned with describing a rigorous and robust approach to the definition of an experimental program.

This chapter starts by describing the design principles adopted and then uses these to specify an experiment design before considering the inference this has on the data collected with a view to the subsequent analysis. The chapter concludes by integrating design principles, design and analysis into a validation of the approach taken.

6.1 Design Principles

> *"An experiment is a series of tests in which purposeful changes are made to the input variables of a system so that we may identify the reasons for change that may be observed in the system response*.
> "   (Montgomery, 2009, p.1)

The primary purpose of any experiment is to reveal the factors that have an impact on a phenomenon of interest and in so doing establish their relationship (if there is one) with the phenomenon (usually expressed as a system response). Furthermore, as any computer model design inevitably incorporates a degree of abstraction it is vitally important that any experiments are robust and repeatable.

There are two fundamental strategies to experiment design. The first accepts that independent variables do not interact and therefore each variable can be varied in turn. This variation of one variable at a time is often referred to as an OVAT strategy. The second strategy assumes that the independent variables may interact and the experiment design has therefore to account for all of these interactions. In this case each combination of variables is referred to as a treatment.

In adopting the CAS perspective it is clear that any experimental design should accept that the independent variables could interact, which in turn guides the experimental design to a variation of what is generally termed a factorial design. A full factorial experimental design includes every possible combination of variables and is the most complete of the factorial designs. The feasibility of a full factorial design depends on two considerations: the number of variables and the number of levels of those variables that need to be taken into account. An experiment with five variables with two levels for each variable will require 32 treatments, however if three variable levels are used then the number of treatments increases to 243.

It therefore follows that the design possibilities are a function of the number of independent variables and the number of levels that it is appropriate to vary these variables over. Furthermore, the experimental design may need to account for a number of nuisance variables; variables that are not of direct interest to the research but may have an effect on the response variable. These can be controlled by randomly varying their values within a number of repeated experiments.

The design of an appropriate experiment can therefore be distilled into three principle components: 1) selection/design of appropriate response variables, 2) robustness (how to control nuisance variables), and 3) the choice of appropriate factors that influence the response variable (Montgomery, 2009). The following sections will consider each of these principles in the context of developing an experiment design suitable for answering the research questions.

Montgomery (2009,p.14) provides a useful set of guidelines that encompasses the basic principles described above, specifically:

1. a clear recognition and statement of the problem
2. selection of the response variable (a reflection of the phenomenon of interest)
3. choice of factors, levels and ranges
4. choice of experimental design
5. statistical analysis of the data
6. conclusions and recommendations

The above framework will be used as a structure for the following sections.

6.1.1 Selecting a Response Variable

The first step in any experiment design is to establish the system response variable. Clearly the phenomenon of interest is supply network disruption as a consequence of normal operations.

Disruption has previously been defined as a special class of disturbance which requires a re-organisation of the relationships. Therefore a reasonable operationalisation of a measure of disruption is the size of relationships that are dissolved or created. The measure of disruption in the model is operationalised according to the following algorithm:

- *At each tick*
    - *For each agent*
        - *Compare list of suppliers with previous list of suppliers*
        - *Record any changes in supply (agent and magnitude)*

The above algorithm records the detail of structural changes to the relationships that define a network.

For the purposes of clarity it is worth considering how this algorithm acts in the more difficult context of a change from single sourcing to dual sourcing. In this context the algorithm would only record the new relationship as a structural change to the network. Alternatively, in the opposite circumstance where a buyer changes its strategy from dual to single sourcing, the algorithm records the dissolved relationship.

The algorithm therefore only records structural changes to the network in terms of the amount of demand the buying agent allocates/allocated against a specific supplier.

The disruptions described above can only be caused by changes in risk perception, changes in attractiveness, or agents ceasing to trade, which anchors them in the normal operation of the network.

However, it is also necessary to recognise that the model contains a number of variables (not of primary interest) whose impact on the response variable is not known. These are generally known as nuisance variables and their consideration in the experiment design is described in the next section.

6.1.2 Dealing with Nuisance Variables

Robust experiments require that nuisance variables are controlled so that the effect of the primary independent variables can be tested in a range of contexts reflected in different configurations of the nuisance variables. In this way the robustness of any effects on the response variable generated by the independent variables of interest can be established.

The effect of nuisance variables can be minimised by randomising the variable values and repeating the experiments using different values. In computer experiments this typically necessitates assigning stochasticity to variables that are likely to vary in the real world and repeating experiments with alternative (randomly generated) values for these nuisance variables.

An essential element of a CAS is its critical organisation and its far from equilibrium state. This implies that a CAS's specific behaviour will be sensitive to its initial conditions, although the system's response will not be without structure or pattern. The structures that persist through ranges of initial conditions can be considered fundamental (Choi et al., 2001a; Bak, 1999; Dooley and Van, 1999).

This raises the question of what variables should be controlled for (randomised) and which ones should be considered influencing factors. The guiding principle in this design is that factors that influence the central dynamic of supplier selection and supply strategy should be considered as factors and other variables should be randomised. As a consequence, the variables included in the model can be organised into three categories: 1) those that are emergent and change as the networks evolves; 2) those that describe the initial conditions; and 3) those that persist throughout the experiment.

The variables that emerge as the network evolves include such factors as supplier quality, financial stability, and price. These variables guide agent behaviour but are not of primary interest in this research; nevertheless they cannot be simply discarded, and in accepting a CAS perspective they must be allowed to influence the system. Essentially, these three variables form part of the supplier selection criteria and reflect an agent's historic attractiveness. The one agent variable that stays fixed throughout any experiment is location.

Location impacts on supplier selection and therefore also on supply risk, agent financial stability, and price; furthermore, the agent is not permitted to modify its location, making location a nuisance variable. This can be controlled by adopting an experimental strategy that includes repetitions where this variable is randomly varied so that any persistent observations are clearly not a consequence of agent location.

The price variable also assumes an initial value which can be considered a proxy for the agent's unique history, as such the initial price also represents a nuisance variable which also needs to be accounted for through repetitions using randomised values.

Having identified the nuisance variable and established the basis for how experiments can be replicated to control for these nuisance variables the next section will consider the selection of factors or variables that impact the system response and are of interest in answering the research questions.

6.1.3 Choice of Factors Impacting the Response of the System

The second step in any experiment design is the logical or theoretical anchoring of variables that relate to the phenomenon of interest.

As this thesis is primarily interested in the dynamic character of a supply network, the primary mechanism for defining structure is found in the supplier selection process. Buyers select suppliers to develop their competitive advantage, which in the context of industrial marketing is primarily a reflection of their attractiveness to their potential customers balanced with a consideration of how to manage supply risk.

The initial conditions of a market can be described by vertical and horizontal levels of differentiation. These values describe the differentiation in price between the various tiers of the market, and also the level of variation within a tier. In the real world these values are not artificially constrained and are a function of scarcity of supply and demand (as previously described in section 3.2.1).

These conditions can be framed in a way that allows them to persist through the duration of the experiment, in other words they represent constraints within which the agents must act.

In parameterising market conditions two assumptions have been made:

- Raw material price is fixed at some assumed level
- The parameterisation range should allow the price ranges in tiers to both overlap and be clearly differentiated

The literature also revealed that two key behaviours were likely to impact the dynamics of a supply network: collaboration and adaptation in terms of price competition. The operationalisation of these behaviours within the model specification permits agents to modify their existing behaviour in consideration of their perceptions of risk and experienced demand. In other words, the behaviours cannot be controlled directly from outside the model.

However, whether or not an agent is permitted to collaborate or adapt its pricing to attract more customers defines two scenarios within which the impact of market structure can be specified exogenously and comparisons across these scenarios be made.

Finally, Priogine (1997) amongst others noted that complex systems can operate far from equilibrium, partly because the systems are not closed with resources being allowed to flow in and out of the system or in the case of this thesis the network. This presents another scenario within which both the impact of market structures, collaborative capability and price competition can be evaluated.

Fundamentally the literature reviewed and the model specification can be synthesised to develop a framework of experimentation which is summarised in Figure 6.1.

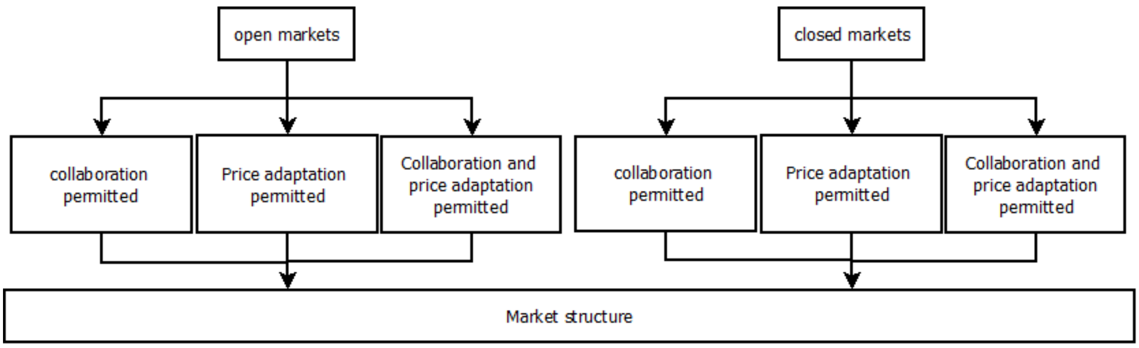


Figure 6—1: Experimental framework

Having established a framework which specifies the variables of interest that impact the response variable it is necessary to consider what the appropriate range and number of levels over which these variables should be.

6.1.4 Levels and Range of Variables

6.1.4.1 Market Structure

Before deciding how many levels should be applied to each variable that defines market structure, it is necessary to define how these variables are used.

Market structure is defined along two dimensions: vertical and horizontal. The vertical structure is bounded by two values: raw material costs and mean retail price. This requires the specification of the mean manufacturing margin and the wholesale mean margin.

The horizontal structure is bounded by the minimum and maximum price for each tier; however, it should be noted that the maximum retail price has already been specified. The horizontal market structure therefore requires the specification of the retail price variation, the wholesale price variation and the manufacturing price variation.

Key: MMM: manufacturing mean margin, MWM: mean wholesale margin, MPV: manufacturing price variation, WPV: wholesale price variation, MRP: maximum retail price and RPV: retail price variation

summarises the logic of the market structure which can be defined by five variables: manufacturing mean margin, mean wholesale margin, manufacturing price variation, wholesale price variation and retail price variation; and two fixed values, raw material price and maximum retail price.

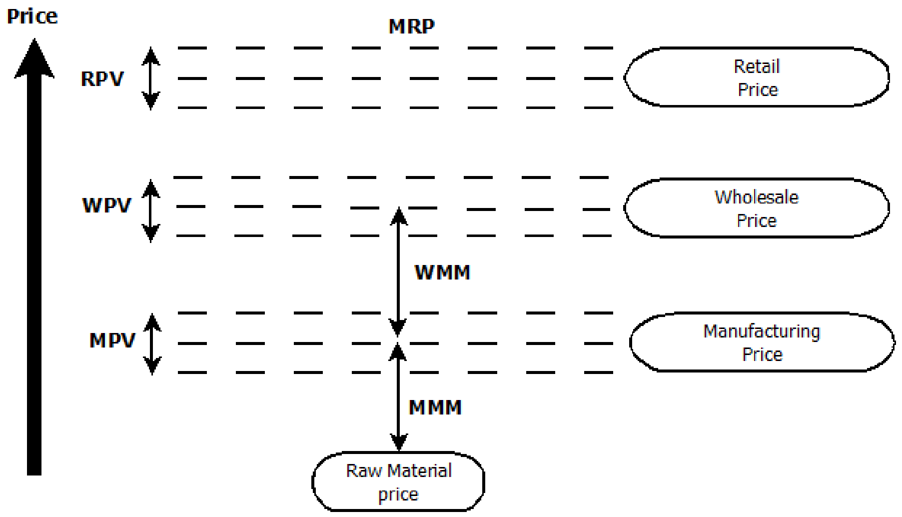


Figure 6—2: Market structure logic

Key: MMM: manufacturing mean margin, MWM: mean wholesale margin, MPV: manufacturing price variation, WPV: wholesale price variation, MRP: maximum retail price and RPV: retail price variation

In designing an experiment to establish whether or not there is any relationship between market structure and a network's vulnerability to disruption, it is necessary to decide what variables should be used, how many levels should be tested, and what values should be used for each level.

Having shown that the market structure can be defined by five variables with two assumptions, consideration needs to be given to how many levels should be used to adequately describe the system/network conditions. As general guidance linear relationships can be described by two levels, and curves by three.

Each of the five variables describing market structure when considered in isolation have a positive/negative relationship with diversity, and diversity in a CAS has been used as a proxy for resilience and robustness (e.g (Bonabeau, 2007; Nair and Vidal, 2011; Cunha and Joao Vieira da Cunha, 2006; Allen et al., 2006). For the purposes of clarity the variables can be considered as two groups: the first defines how close the tiers of the network are in terms of supply price, and the second how close the various agents within a tier are likely to be in terms of price.

Increasing margins of the tiers brings the tiers closer together, thereby making the pool from which a supplier can be selected bigger. This is essentially a positive linear relationship with no minimum or maximum in the relationship between margin and diversity. It therefore seems reasonable to adopt a two level experiment design in this regard.

Increasing the variation in prices within a tier will increase the differentiation of suppliers and reduce the feasible set available for supplier selection within the tier. Once again this appears to be a linear relationship (albeit negative), and consequently a two level experiment design seems valid.

The specification of variable levels is guided by the following assumptions:

1. Manufactures have the highest levels of investment to recover and have the lowest intake costs; therefore, they have the highest margins.
2. Wholesaler's intake costs are greater than manufacturers but their investment is less; therefore, the wholesale margin is less than the manufacturing margin.
3. Retailers have the lowest investment and their margin is less than that of wholesalers.
4. Price variation within any tier is never less than 5% and never more than 20%.

Table 6.1 synthesises the above assumptions into a specification of the market structure variables for the experiment design.

Table 6-1: Specification of market structure variables

Variable	High	Low
Manufacturing mean margin	0.5	0.35
Mean wholesale margin	0.3	0.15
Manufacturing price variation	0.2	0.05
Wholesale price variation	0.2	0.05
Retail price variation	0.2	0.05

6.1.4.2 Permitted Agent Behaviours

The consideration of permitted agent behaviours is simpler than that of market structure in the sense that the behaviour or behaviour combination is either permitted or not. This binary description of permitted behaviours by necessity results in each variable having two levels.

It is also convenient to include whether or not a market is closed or open as a behavioural variable, as to do so facilitates the comparison of agent behaviours in open and closed markets in any subsequent analysis. Furthermore, permitted behaviours, like open or closed market conditions, are expressed at the network level.

Permitted agent behaviours are therefore characterised as three variables with two levels denoting the presence or absence of the behaviours.

6.1.5 Experiment Design and Specification

The third step in the design of an experiment is to establish the appropriate range over which variables should be varied. This is the parameterisation of variables and a fundamental step in establishing the experimental design. The design is translated into a specification by mapping the combination of parameter variations into treatments and blocks.

6.1.5.1 Treatments and Blocks

Treatments refer to variations of a specified parameter, whilst blocks refer to the conditions under which the parameter is varied. The design framework identified two treatment dimensions: permitted agent behaviours and market conditions. This leads naturally to the design of two related experiment designs: 1) an experiment where market structure (treatment) is varied in specified permitted behavioural contexts (blocks); and 2) an experiment where permitted agent behaviours are varied (treatment) in specified market conditions (blocks). This fundamental structure for the design of the experiments will reveal data that permits a complete investigation of how the variables describing both market structure and permitted agent behaviours of collaboration and price competition impact open and closed network disruption responses to normal operations.

Table 6-2 summarises the 32 configurations of market structure, and Table 6-3: the eight configurations of permitted behaviours.

Table 6-2: Market structure configurations

Treatment /Blocks	Manufacturing Price Variation	Manufacturing Mean Margin	Retail Price Variation	Wholesale Price Variation	Mean Wholesale Margin
1	High	High	High	High	High
2	High	High	High	High	High
3	High	High	High	High	High
4	High	High	High	High	High
5	High	High	High	High	High
6	High	High	High	High	High
7	High	High	High	High	High
8	High	High	High	High	High
9	High	High	High	High	High
10	High	High	High	High	High
11	High	High	High	High	High
12	High	High	High	High	High
13	High	High	High	High	High
14	High	High	High	High	High
15	High	High	High	High	High
16	High	High	High	High	High
17	High	High	High	High	High
18	High	High	High	High	High
19	High	High	High	High	High
20	High	High	High	High	High
21	High	High	High	High	High
22	High	High	High	High	High
23	High	High	High	High	High
24	High	High	High	High	High
25	High	High	High	High	High
26	High	High	High	High	High
27	High	High	High	High	High
28	High	High	High	High	High
29	High	High	High	High	High
30	High	High	High	High	High
31	High	High	High	High	High
32	High	High	High	High	High

Table 6-3: Permitted behaviours configurations

Treatments /blocks	Permitted Behaviours			
	Collaboration	**Price competition**	**Open Market**	**Closed Market**
1	No	No	No	Yes
2	Yes	No	No	Yes
3	No	Yes	No	Yes
4	Yes	Yes	No	Yes
5	No	Yes	Yes	No
6	Yes	Yes	Yes	No
7	Yes	No	Yes	No
8	No	No	Yes	No

6.1.5.2 Replications

Having specified the levels of the logically argued treatments and blocks the final component of the experimental design is the number of replications that are required to control for the nuisance variables.

In noncomplex systems this generally involves using statistical methods to define sampling and repetition regimes. However, as already established, CASs are non-deterministic in that they are non-linear, path dependent and emergent. Levin (2002) eloquently summarised these characteristics as:

> *"The study of complex adaptive systems is the study of systems limited in their predictability. Because complex adaptive systems are systems in which microscopic interactions and evolutionary processes give rise to macroscopic phenomena through nonlinear interactions, these systems are subject to path dependence, with implications for the likelihood of multiple stable states, chaotic dynamics and frozen accidents*."

The characteristics of a CAS therefore precludes any statistical basis for determining the number of repetitions required to satisfy the prescribed confidence limits. However, the observations made by Bak (1999) and the limits of practicality regarding how many simulation runs can be made with the available computational resource can be combined to determine *ex* *post* whether or not the number of repetitions provides sufficient data to develop a good fit model for the cumulative distribution of disruption events.

Give the length of time it takes to run a single simulation of 1000 days and the number of treatments and blocks, the initial level of replication was set at five. The replication level was tested using the most complex case (maximum diversity and all agent behaviours permitted), and the results were then formally tested against power and exponential cumulative distribution curves.

The results of this experiment to establish whether or not the level of repetition is adequate are summarised in Table 6-4 and Figure 6—3.

Table 6-4: Determination of level of repetition

Model Summary and Parameter Estimates

Dependent Variable: days>magnitude

Equation	Model Summary					Parameter Estimates	
	R Square	F	df1	df2	Sig.	Constant	b1
Power	0.729	4997.436	1	1855	0.000	199729.068	-0.716
Exponential	0.978	81465.309	1	1855	0.000	1564.144	0.000

The independent variable is Magnitude of disruption

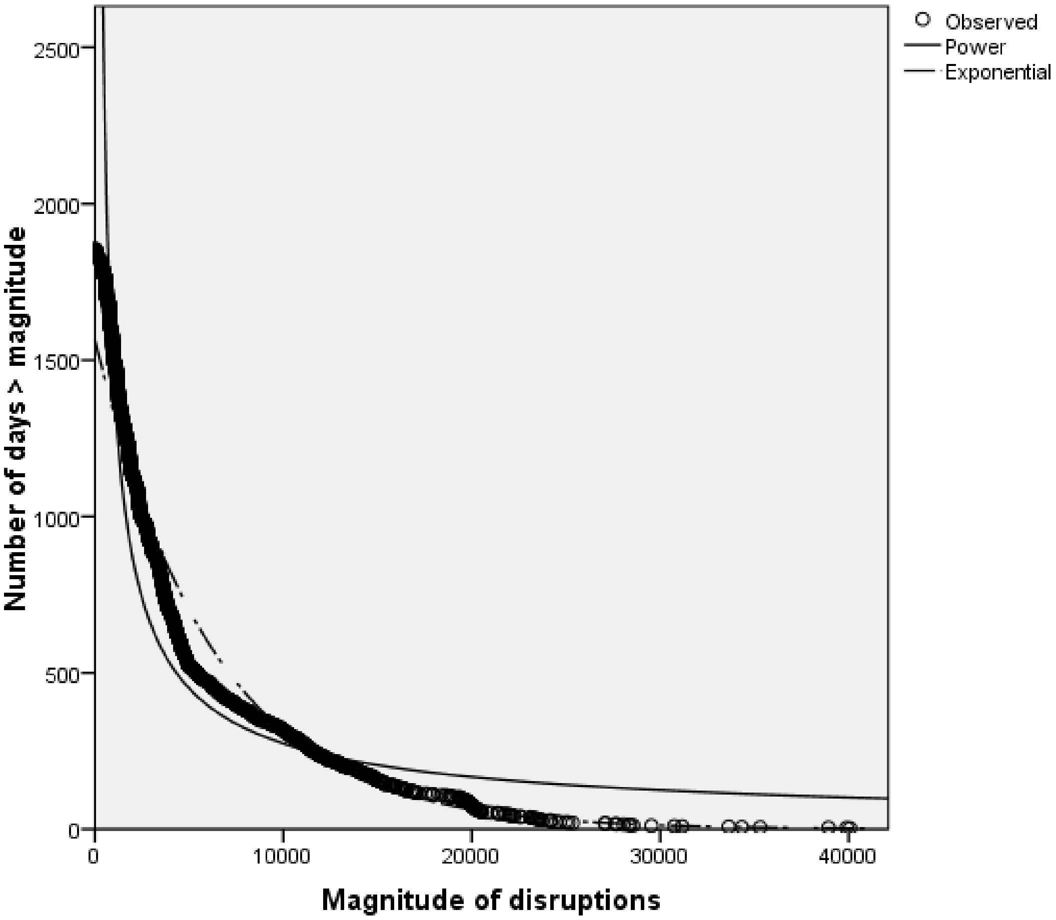


Figure 6—3: Cumulative distribution of disruption events in determining the level of repetition

Parameters: maximum diversity, maximum range of permitted behaviours and five repetitions.

Examination of Table 6-4 and Figure 6—3 shows the cumulative distribution of disruption events can be described as being exponential with an exponent of 1564.144, which explains 98% of the observed variation. This level of fit was deemed acceptable as it provided a high level of explaining power and was affordable in terms of the computing power available. As a consequence the number of repetitions was set at five which would require just over 1300 hours of simulation.

6.2 Summary

The experiment design is structured as two experiments which alternately take market structure and permitted behaviour as treatments and blocks. Experiment

1 is configured as a five factor (market structure), two level factorial experiment with eight permitted behaviour blocks. Experiment 2 is configured as a three factor (permitted behaviours), two level factorial experiment with 32 market structure blocks.

Each experiment generates 256 cases, each being described by a unique combination of market structure and permitted behaviours and repeated with 5 different random seeds. These experiments permit data to be collected for 1000 simulated days. Each case is controlled for the nuisance variables of location and price by repeating the simulations with different random number seeds.

The following chapter will describe the data collected from these experiments and their subsequent analysis with the intent of directly answering the research questions developed in consideration of the extant literature summarised in Chapter 3.

7 Findings

The previous chapters have addressed the underpinning theories, operationalisation of normal operations, model specification, and experiment design. This chapter will present the results from the experiment through a lens of appropriate analysis which allows answers to be developed regarding the research questions specified in Chapter 2.

The chapter will begin with a generalised description of the results which will be used to frame the subsequent statistical analysis. The statistical analysis will identify cases framed by the experiment design which are statistically different before applying *post hoc* tests to develop explanations for the differences observed. The chapter concludes by synthesising the results into coherent answers to the questions posed.

7.1.1 Testing for a Significant Difference

The statistical testing of the difference between experimental treatments is the primary tool used to establish whether or not the treatment influences the networks vulnerability to disruption.

There are two primary tests that can be used to establish statistical difference between samples: the first is a comparison of means and assumes a normal distribution within the sample (e.g. analysis of variance or ANOVA), whilst the second does not assume any distribution and is generally described as non-parametric.

It is not possible to assume that the distribution of disruption events follows a normal distribution, and in fact the literature suggests that it will not (Bak, 1999). It is for this reason that non-parametric tests will be used to test whether or not there is any statistical difference between different treatments.

For the purposes of clarity it is important to understand the broad principles on which non-parametric tests are designed. The simple assumption underpinning all these tests is that if the treatments are similar then when the treatments are aggregated and ranked (for example by the number of days on which disturbances exceed a particular value), then there should be an even distribution of data drawn from the treatments throughout the ranked results. Alternatively, and uneven distribution would suggest that the treatments were significantly different.

The most common non-parametric test of statistical significant difference is the Kruskal-Wallis test, which will be used in the analysis of treatments in this chapter.

7.2 Generalised Description of the Results

The experimental design resulted in two experiments each with 256 cases. Each case represented a unique combination of market conditions and permitted behaviours.

Aggregated results over the simulated period can be used to give some indication of how cases compare in terms of the total disruption experienced. These results are merely a sum of the disruptions over 1000 simulated days and five repeated simulations with different random seeds. These results are presented in Table 7-1.

Table 7-1: Aggregated results over the simulated period

		Market Structure															
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Permitted Behaviours	**1**	4394318	944598	5052780	306146	1101512	2232806	176699	1376184	1838036	848961	247339	1726636	2271738	942626	871867	1477839
	2	324309	1110998	1238483	854364	1510765	1355881	447512	1109575	706869	884364	207296	1389784	797250	1337119	459036	1536882
	3	1069187	2268380	1310070	909360	813059	811581	197496	5126657	1504547	889421	1701132	2325755	361992	1330056	2482427	1920839
	4	2367242	2411356	1915170	1543313	2076821	2162805	2054242	2241208	2237625	2016609	2006532	2296905	2084622	2530200	2133693	2591986
	5	5672873	2951956	2689239	4162864	7948773	5157728	4143863	3740697	3152642	4159601	2766624	4137340	5839044	2945320	2975417	6072073
	6	8427767	9582124	7586435	8074854	6675772	8471757	5594101	6849870	10174114	10454710	8721207	5831474	5484274	4713483	7002221	13092852
	7	6300286	5291983	7928616	6401896	2631488	2859055	7121542	9291380	4190407	7586454	6452416	5408757	5368229	6330914	4474030	5318029
	8	3434060	6388942	3038966	4700065	3848152	4844238	7190577	2574638	6912519	9868102	5922741	6478889	4505310	5437356	2493202	4313771

		Market Structure															
		17	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**
Permitted Behaviours	**1**	578152	3873171	4877960	728028	3341759	1741636	2350105	727131	2950498	1339185	751744	2027950	5080777	238578	1189582	1748437
	2	1224802	407331	311463	861316	2785788	1162709	1755569	750287	946752	2527545	1407582	640580	521241	2075442	716111	1207298
	3	284110	6613895	190932	2074561	766238	1350411	811839	778972	448885	528712	5451999	668642	453785	281036	171201	1302210
	4	2114245	2092494	1982986	2097577	2651088	2142208	1826344	1919037	2041475	2484204	2238444	2147467	1586621	2181115	2423430	2110604
	5	3404973	5347584	2911507	3499326	4437353	4923255	3453138	4159320	2326317	10479686	5572716	5360593	4023154	4392485	3464618	3728421
	6	8025939	13631581	5338817	10504215	5208408	6668124	5721360	11253385	13172955	7151271	8076865	8207445	6078472	17678303	12166012	9615080
	7	2303760	10231487	4109819	8074500	5842002	3023487	3562840	8566151	1924570	6198622	5240989	5748643	8995750	6646792	3853298	6694020
	8	3103834	3763654	2511263	2703157	2786700	4208980	3946662	4866652	4937456	3146554	6347900	8799438	4260711	3336689	4235177	4425984

Examination of Table 7-1 allows comparisons to be made within the columns or rows. The rows represent the results for experiment 1 (where the permitted behaviours are fixed and the market conditions varied), whereas the columns represent the results for experiment 2 (market conditions fixed and permitted behaviours varied).

The first observation that can be made from Table 7-1 is that all combinations of market conditions and permitted behaviours experienced levels of disruption as a consequence of normal operations. This generalised observation poses a number of more interesting questions:

- Are the observed disruptions symptomatic of supply networks being CASs?
- Are closed networks different to open networks?
- Is there any significant difference between cases as defined by market conditions and permitted behaviours?

7.3 Research Question 1

> *Do supply networks comprising multiple connected supply chains experience periods of disruption as a consequence of normal operations?*

This question is framed by an assertion that supply networks behave as CASs and therefore are vulnerable to normal accidents as described by NAT. As such, the question can be reduced to two testable hypothesises:

> *H1: The pattern of cumulative distribution of disruptions experienced by a network under any of the permitted behaviours and market conditions conforms to an exponential law description*

To understand whether or not the observations can be related to the concept that supply networks are CASs it is necessary to estimate the curves of the cumulative distributions. The results of this analysis are shown in Table 7-2.

Table 7-2: Model summary and parameter estimates

Scenario	Equation	Model Summary					Parameter Estimates	
		R Square	F	df1	df2	Sig.	Constant	b1
1	Exponential	0.466	18048.602	1	20713	0.000	667.227	0.000
2	Exponential	0.663	20762.331	1	10568	0.000	366.282	0.000
3	Exponential	0.338	7473.901	1	14620	0.000	459.962	0.000
4	Exponential	0.840	63860.786	1	12177	0.000	398.683	0.000
5	Exponential	0.748	102687.909	1	34606	0.000	835.818	0.000
6	Exponential	0.792	192140.930	1	50451	0.000	1179.749	0.000
7	Exponential	0.813	161755.807	1	37120	0.000	819.785	0.000
8	Exponential	0.719	105991.962	1	41495	0.000	932.674	0.000

The dependent variable if CoM
The independent variable is SumOfMagnitude.

Table 7-2 shows that the R square value for closed market behaviours is less than open market behaviours, an observation that may be indicative of the network deviating from the expected behaviour of a CAS, or it could be that the permitted behaviour level of analysis is too coarse. A more granular examination of deviations from an exponential description shows…..

The graphical representations were primarily used to establish whether or not the network's experience of disruptions allowed it to be described as a critically organised CAS. The initial graphical analysis takes the form of a least squares regression approach to curve estimation for each of the 256 treatments. For the sake of brevity Table 7-3 reports only those cases where the R Square value is less than 0.7 on the basis that the other models provide good fits (an example of a more complete set of results is given in Appendix B, although it shoud be noted that a full set of results would require in excess of 64 pages).

Table 7-3: Least squares regression for curve estimation for H2

		Model Summary					Parameter Estimates	
Case	Equation	R Square	F	df1	df2	Sig.	Constant	b1
105	Power	.615	713.313	1	446	.000	13860800.991	-1.499
	Exponential	.500	445.786	1	446	.000	275.057	.000
106	Power	.642	2358.797	1	1315	.000	35433460.910	-1.541
	Exponential	.532	1493.111	1	1315	.000	1009.325	.000
120	Power	0.547	116.906	1	97	0	5316.842	-0.599
	Exponential	0.606	149.099	1	97	0	93.856	0
125	Power	.200	102.373	1	409	.000	68878.565	-.701
	Exponential	.269	150.679	1	409	.000	670.278	.000
126	Power	.494	534.934	1	549	.000	358776285.167	-1.865
	Exponential	.509	568.790	1	549	.000	659.567	.000
129	Power	.358	619.488	1	1110	.000	139208.487	-.712
	Exponential	.660	2159.216	1	1110	.000	1977.154	.000
304	Power	.338	452.385	1	886	.000	4223005.143	-1.388
	Exponential	.299	377.683	1	886	.000	558.828	-.001
308	Power	.138	132.676	1	831	.000	18516.676	-.478
	Exponential	.460	709.145	1	831	.000	2940.371	.000
314	Power	.689	2087.654	1	944	.000	4233714.848	-1.354
	Exponential	.597	1400.901	1	944	.000	592.342	.000
315	Power	.380	179.799	1	293	.000	5618.155	-.470
	Exponential	.606	451.473	1	293	.000	368.351	.000
822	Power	.695	4299.178	1	1889	0.000	1673511.747	-1.052
	Exponential	.651	3516.613	1	1889	0.000	1367.576	.000

The coding of the cases detailed in Table 7-3 and Appendix B describes the permitted behaviours as the first digit and the second two digits describe the market conditions. For instance, case 315 describes permitted behaviours of collaboration in a closed market under market structures described by a vertical structure (high manufacturing margin, low wholesale margin) and a horizontal structure (low price variation for manufacturers, wholesalers and retailers).

A number of general observations can be made regarding Table 7-3. All but one of the poor fit models are cases describing closed markets and the exponential description of the phenomenon has the best fit which generally supports the theoretical positioning of supply networks as CASs.

The cumulative distribution of disruptions for the cases summarised in Table 7-3 are presented in Figure 7—1. Examination of the Figure 7—1 reveals that a cumulative distribution of disruptions can be described by a series of steps, which whilst following the general pattern of an exponential description with a negative coefficient, deviate significantly from the equivalent graphical descriptions of open systems.

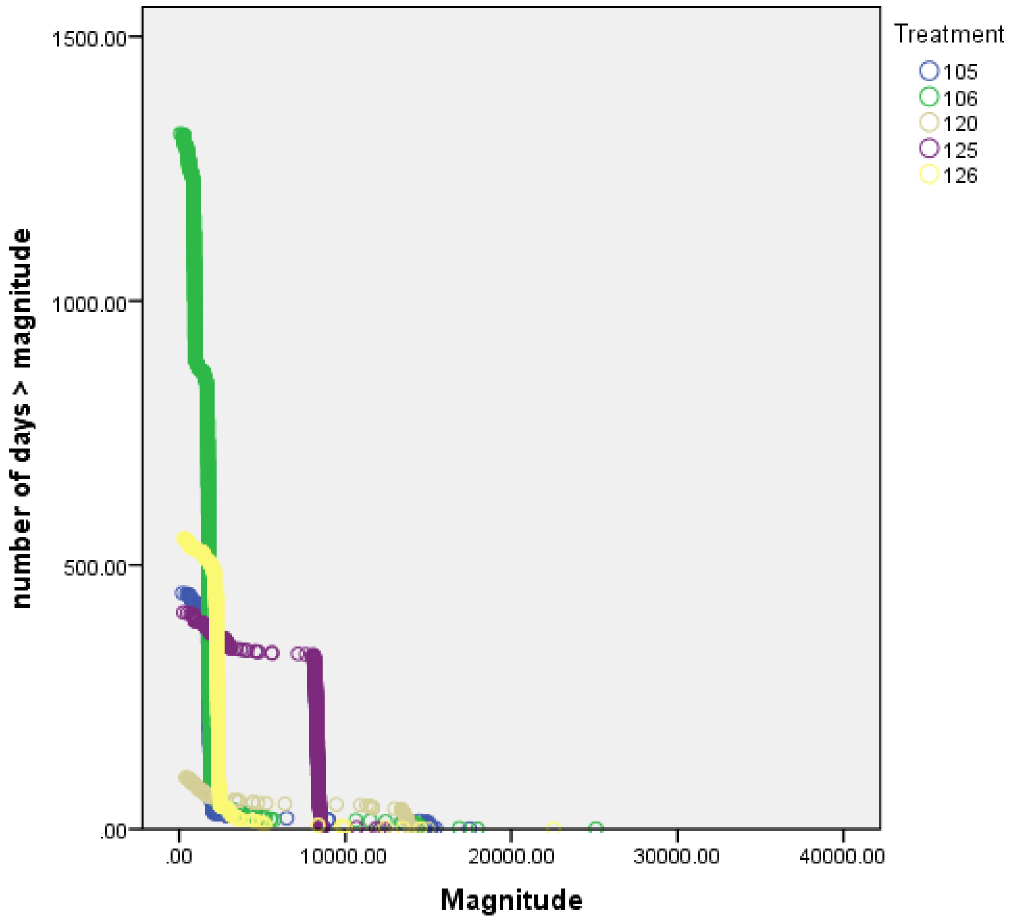


Figure 7—1: Examples of poor fit cumulative distributions

One possible explanation for the observed ‘step’ phenomenon in closed networks may lie in the way in which the constraints on the closed system drive its evolution. In the period immediately after initialisation the network participants have the greatest range of suppliers, then as the network evolves the number of suppliers is reduced until a state of equilibrium (as opposed to a state of far from equilibrium) develops with little or no changes to the population or the associated supply risk. As a consequence, the network participants are increasingly unlikely to change suppliers and the level of disruption is minimised.

For the above argument to hold a plot of available suppliers for the closed system should reveal a state of equilibrium being attained after a period of time. Figure 7—2 shows the supply population dynamics for the exemplar case (105) as having a poor curve fitting to either an exponential or power law distribution of disruption events.

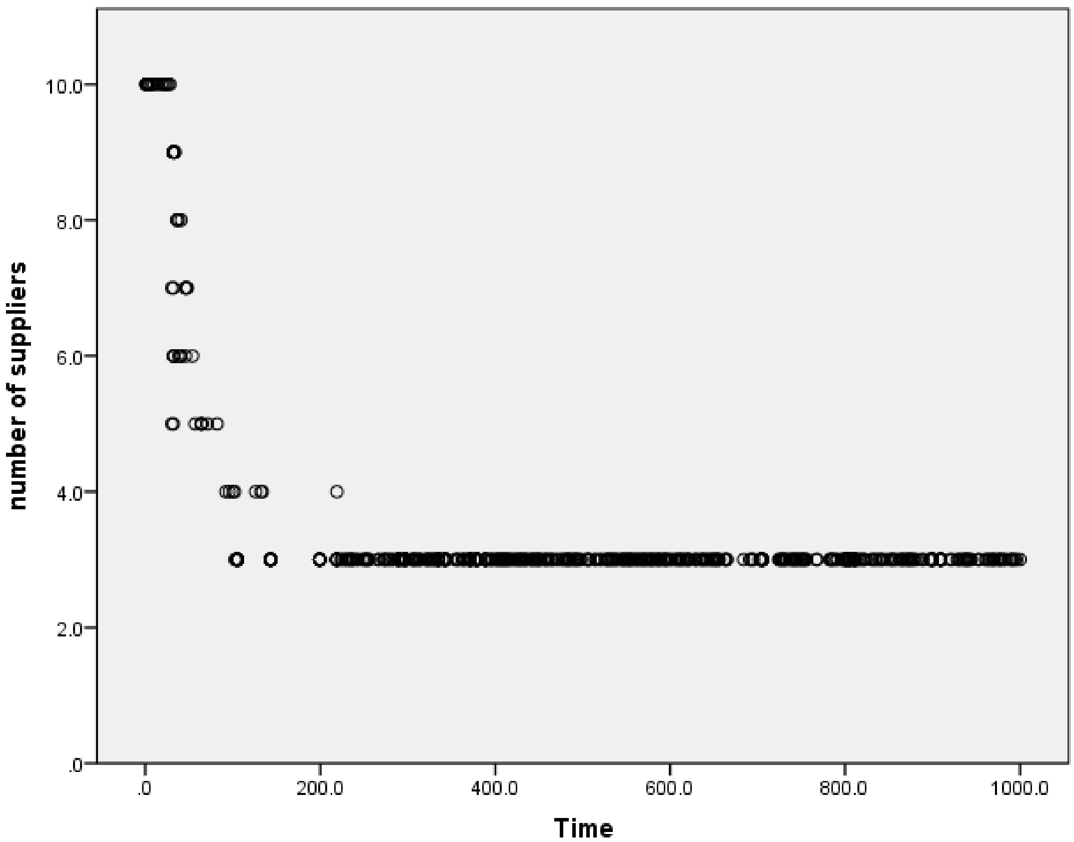


Figure 7—2: Supplier population profile for poor cumulative distribution fit

Further examination of closed market cumulative distributions of disruption responses reveals that the steps identified in the cases presented above are prevalent, although the specific pattern of most cases accepts a 'good fit' description as an exponential law. This observation is supported further when the punctuated equilibrium profiles for closed markets are compared to those of open markets, where once again time based comparisons show how closed markets tend to states of equilibrium whilst open markets tend to far from equilibrium states (Figure 7—3).

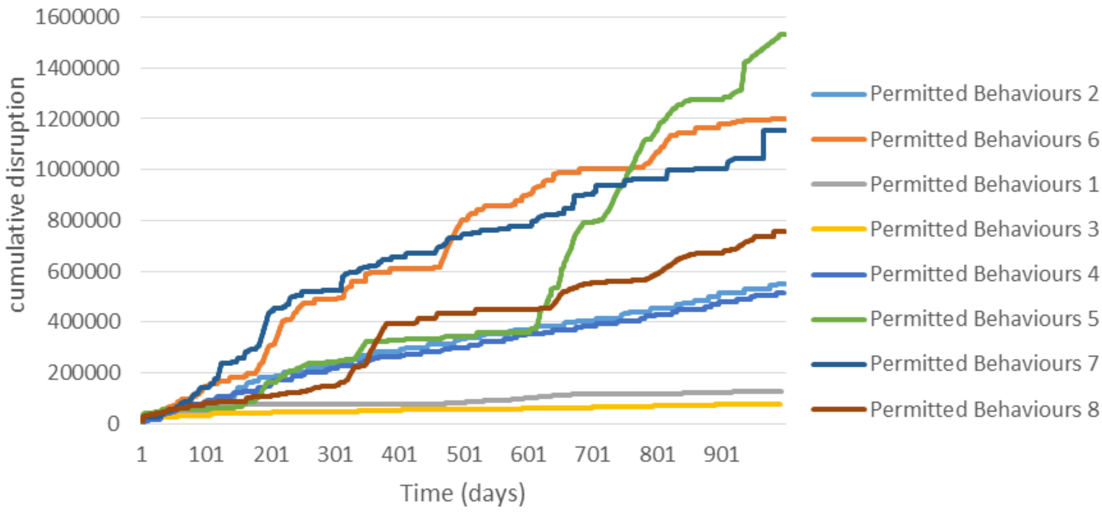


Figure 7—3: Exemplars of punctuated equilibrium for each permitted behaviour

In the context of CASs, the substantive difference between power law and exponential law descriptions is that the exponential distribution tends to zero much quicker than the power law. It is therefore not surprising to find that the exponential description is dominant, as the level of disruption in the experiments is ultimately constrained by fixed demand.

Consideration of the characteristic distribution responses for open networks reveals cumulative distribution patterns that are a much better fit to exponential laws, suggesting that open systems do indeed conform to Baks (1999) definition of a critical organisation.

The observations made above can be statistically supported by considering whether or not there is any statistically significant difference between the R squared statistic for the curve estimations for open and closed markets.

This is achieved through a two-step process: firstly the samples are tested for homogeneity of variances using Levene's non-parametric test of homogeneity of variances, and secondly by applying the Kruskal-Wallis test for significant differences between the ranked means of the sample. The later test assumes homogeneity of variance and therefore justifies the first.

Levene's non parametric test indicated that there was no significant difference in the homogeneity of variance of open and closed markets (f= 8.059 ; p=

0.005) and a Mann-Whitney U test indicated that the R squared values for the exponential curve estimation of open markets were significantly higher than the R squared values for closed markets (Mdn= 0.954 for open markets), U=283592, p= 0.000, r =7945).

However, it should be noted that the *post hoc* analysis of the cumulative distribution R squared values for closed systems was below 0.7, which when considered in the context of the population dynamics and punctuated equilibrium suggests that far from being critically organised closed systems tended to states of neo equilibrium.

H1 is therefore retained for open systems where resources can enter and leave the system resulting in significantly higher R squared values for the curve estimation than closed systems. However, H1 is not retained for closed systems where the R squared values were significantly less than those in the open network and states of neo-equilibrium were observed.

The implications of this finding are significant as the traditional conceptualisation of supply chains and some supply networks is that of a closed network where resources do not enter or exit the network. The results here show that such a network will tend towards a state of equilibrium. However, if resources do in fact enter and exit the network (new suppliers are formed and others become inefficient and exit) then the system is maintained far from equilibrium in a critical state and will experience significant disruptions as a consequence of nothing more than normal operations.

This is not to say that supply chain conceptualisations are inappropriate; they have provided the sound basis on which the practice of supply chain management responds to the dynamics of the market. However, when considering the balance between efficiency and risk mitigation ,and in particular the mitigation of systemic network risk, the findings of the experiment suggest openness of the network should be taken into account.

The next two research questions were formulated to develop a deeper understanding of two parameters on a supply network's vulnerability to disruption as a consequence of normal operations.

7.4 Research Question 2

What is the impact of market structure on the level of disruption experienced by networks?

The second research question is formed from the theory describing CASs which posits that the disruption response of a CAS, and therefore a supply network, is sensitive to initial conditions. This can be framed by the following hypothesises

H2: there is no difference in the magnitude of disruptions experienced by networks with different market conditions in any of the permitted agent behaviours combinations considered

As with the previous hypothesis, the results for each permitted behavioural block are first tested for heterogeneity of variance. Three blocks of permitted behaviours showed a significant difference between the differences of ranked means of variation according to Levene's non-parametric test for heterogeneity. *A post hoc* Tukey analysis found that in all these cases only one homogenous grouping was identified

Table 7-4: Levene's and Kruskal-Wallis test results for H2

		Levenes Test						Kruskal-Wallis			
		Sum of Squares	df	Mean Square	F	Sig	Post Hoc Tukey Results	Null Hypothesis	Sig	Outcome	Post Hoc Pairwise Comparisons
Permitted Behaviour	1	18681.854	31	602.640	1.209	.231	N/A	The distribution of total magnitude of disruptions is the same across all market conditions	0.452	Retain the null hypothesis	N/A
	2	14943.616	31	482.052	.981	.504	N/A		0.678		N/A
	3	17325.692	31	558.893	1.229	.212	N/A		0.05		N/A
	4	22227.008	31	717.000	1.529	.053	N/A		0.609		N/A
	5	23834.751	31	768.863	2.074	.003	Only 1 homogenous subgroup identified		0.592		N/A
	6	17375.740	31	560.508	1.180	.258	N/A		0.048	Reject the null hypotheis	
	7	25145.887	31	811.158	1.633	.031	Only 1 homogenous subgroup identified		0.524	Retain the null hypothesis	N/A
	8	24341.479	31	785.209	1.73	0.019	Only 1 homogenous subgroup identified		0.867		N/A

Levene's non parametric test indicated that there was no significant difference in the homogeneity of variance of open and closed markets (f= 8.059 ; p= 0.005) and a Mann-Whitney U test indicated the R squared values for the exponential curve estimation of open markets were significantly higher than the R Squared values for closed markets (Mdn= 0.954 for open markets), U=283592 , p= 0.000, r =7945).

Subsequent Kruskal-Wallis non-parametric testing found only one permitted behaviour indicated a significant difference in the magnitudes of disruption across the different market conditions (Mdn= 0.954 for open markets), U=283592 , p= 0.000, r =7945). Subsequent *post hoc* Kruskal-Wallis with Bonferroni correction testing indicated no significant difference in the magnitude of disruptions for the different market conditions for these permitted behaviours (Mdn= 0.954 for open markets), U=283592 , p= 0.000, r =7945).

Whilst the above analysis addresses total disruptions experienced over a 1000 simulated period it does not compare the characteristics of the disruptions experienced. Unfortunately, the closed market cumulative distribution of disruptions does not follow an exponential law description and comparisons between the variation in exponents and constants is precluded.

It therefore follows that H2 is accepted and no significant effect on the total magnitude of disruptions experienced by the network over a 100 day simulated period can be established.

7.5 Research Question 3

> *What is the impact of price competition and collaboration between supply chain participants on the level of disruption experienced by the network?*

CAS theory also predicates that agency, and therefore behaviour, is an important mechanism in determining the system or network's disruption response. This can be formally stated as:

> *H3: There is no significant difference between the magnitudes of disruptions experienced by networks with different permitted behaviour across all the considered market conditions.*

The above hypothesis can be tested by a similar process to those used to test the previous hypothesises and he results are summarised in Table 7-5.

Table 7-5: Least squares regression for curve estimation for H2

Market Conditions	Levenes Test						Kruskal-Wallis			
	Sum of Squares	df	Mean Square	F	Sig	Post Hoc Tukey Results	Null Hypothesis	Sig	Outcome	Post Hoc Pairwise Comparisons
1	541.312	7	77.330	8.890	.000	2 homogenous groups identified		0.001		2-6; 2-5
2	111.452	7	15.922	.707	.666			0.002		1-6; 2-6
3	570.780	7	81.540	6.453	.000	3 homogenous groups identified		0.012		No significant differences identified
4	172.284	7	24.612	1.590	.174			0		3-6; 1-6
5	144.252	7	20.607	1.092	.392			0.001		1-6; 3-6; 1-5; 3-5
6	329.020	7	47.003	1.932	.097			0.009		3-6;
7	267.490	7	38.213	4.646	.001	2 homogenous groups identified		0		3-6;
8	312.188	7	44.598	1.641	.160			0.014		No significant differences identified
9	285.084	7	40.726	1.777	.127			0.004		2-6; 1-6
10	316.864	7	45.266	3.250	.010	2 homogenous groups identified		0.001		1-6;
11	306.544	7	43.792	3.184	.011	2 homogenous groups identified		0		2-7; 2-6; 1-6
12	242.300	7	34.614	1.132	.368			0.011		No significant differences identified
13	353.276	7	50.468	3.335	.009	2 homogenous groups identified		0.001		3-5; 3-6
14	346.880	7	49.554	2.490	.037	1 homogenous group identified		0.019		No significant differences identified
15	437.052	7	62.436	3.16	0.012	2 homogenous groups identified	The distribution of total magnitude of disruptions is the same across all permitted behaviours	0.006	Reject the null hypotheis	2-6
16	147.964	7	21.138	.791	.600			0.016		1-6
17	123.248	7	17.607	1.299	.283			0		3-5; 3-6; 1-6
18	516.976	7	73.854	3.87	0.004	2 homogenous groups identified		0.006		2-6
19	372.336	7	53.191	2.968	.016	2 homogenous groups identified		0.002		3-6; 2-6
20	259.708	7	37.101	1.928	.097			0.001		1-6; 2-6
21	320.512	7	45.787	1.574	.179			0.019		3-6; 2-6
22	255.612	7	36.516	1.323	.272			0.006		No significant differences identified
23	512.832	7	73.262	4.033	.003	2 homogenous groups identified		0.016		3-6
24	153.404	7	21.915	2.069	.076			0		2-7; 2-6; 1-7; 1-6
25	237.680	7	33.954	2.140	.067			0		3-8; 3-6; 1-6; 2-6
26	269.084	7	38.441	1.869	.108			0.001		3-6; 3-5; 1-5
27	346.076	7	49.439	3.185	.011	2 homogenous groups identified		0.023		1-6
28	223.932	7	31.990	2.016	.084			0		3-8; 2-8
29	223.292	7	31.899	1.536	.191			0.001		3-6; 2-6
30	258.300	7	36.900	3.582	.006	2 homogenous groups identified		0		1-7; 1-6; 3-6
31	314.752	7	44.965	4.676	.001	2 homogenous groups identified		0		3-5; 3-6; 2-6
32	314.752	7	44.965	4.676	.001	6 homogenous groups identified		No comparison of means possible		

Levene's test for homogeneity of variances showed that in all cases except one the cases could be defined by no more than two homogenous groups, permitting constrained testing using the Kruskal-Wallis test for significant differences in the ranked means. Before considering the analysis of the groups with homogeneity of variance, it is worthwhile examining the exception to the general observation.

Levene's non parametric test indicated that there was a significant difference in the homogeneity of variance for market conditions 32. The inference of this result is that in the context of these market conditions the variation in total disruption across the range of permitted behaviours is significant and not suitable for analysis using the Kruskal –Wallis test for significant differences.

Considerate of the disruption response generated by market conditions 32 inspection of Table 7-5 suggests three immediate observations: 1) market conditions 22 shows no significant difference in mean rankings; 2) permitted behaviours 6 dominates the comparisons for significant differences in disruptions; and 3) market conditions 28 is the only exception to the previous observation as it contains a significant difference in disruption responses described by contrasting permitted behaviours 8 with 2 and 3. Further examination of the full set of results confirms the preliminary observations with permitted behaviours 6 and 8 experiencing significantly higher magnitudes of disruption than a range of closed network permitted behaviours in all but 2 cases. Furthermore, examination of the ranked means for market conditions 32 shows that permitted behaviour 6 also has the highest ranked mean of disruptions for that case.

Inspection of the cumulative distributions of disruption for market conditions 22 (Figure 7—4) does not directly challenge the dominance of permitted behaviours as the context in which the greatest magnitude of disruptions are found.

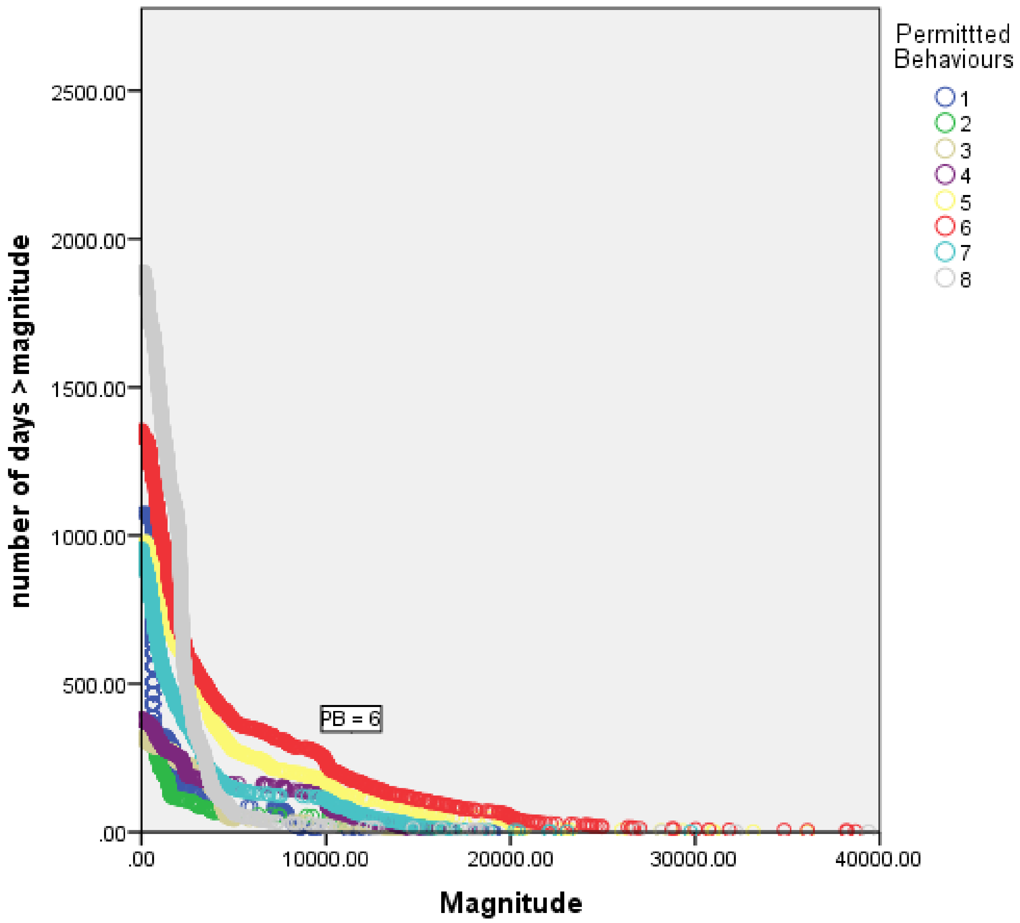


Figure 7—4: Experiment 2 cumulative distributions of disruption for market conditions 22

A similar inspection of the cumulative distributions of disruption for market conditions 28 (**Error! Reference source not found.**) reveals a similar narrative ith little observable difference between the disruption response for permitted behaviours 6 and 8. However, this analysis also draws attention to the fact that permitted behaviours 8 reflects open markets with no collaboration and no price competition, highlighting the significance of the open market element of both permitted behaviours 6 and 8.

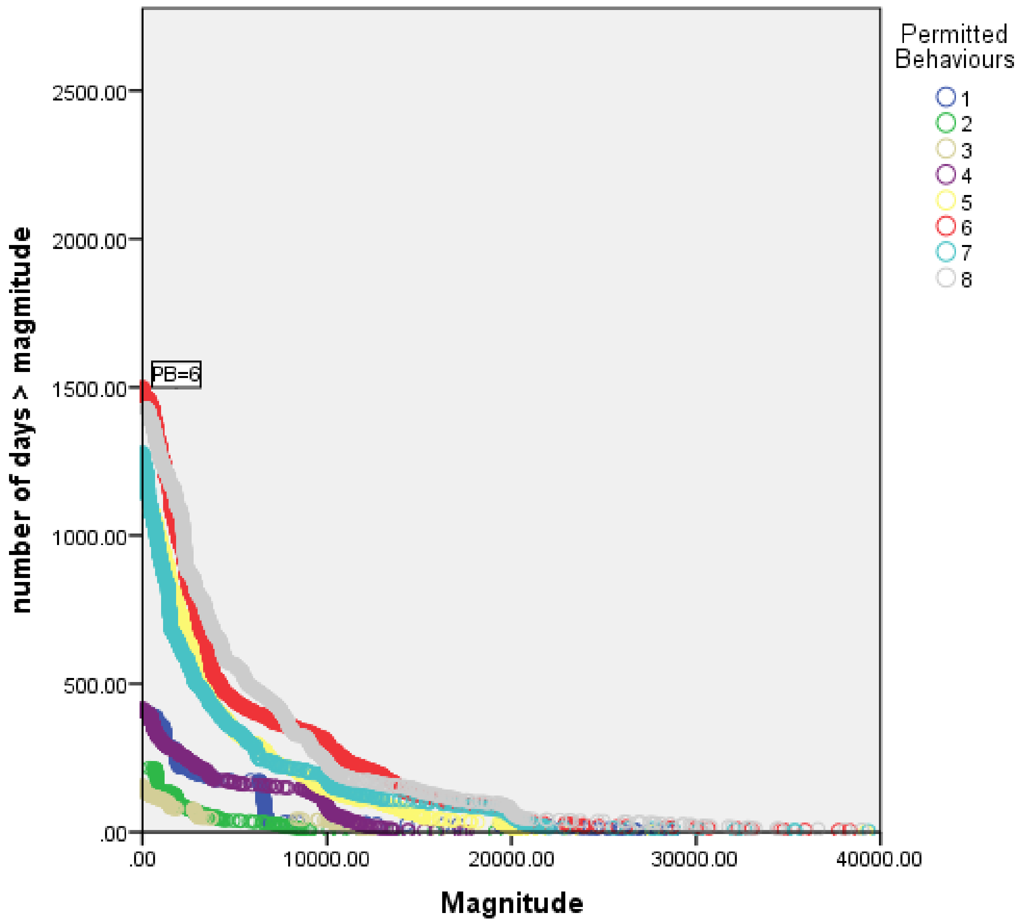


Figure 7—5: Experiment 2 cumulative distributions of disruption for market conditions 28

The experiment also identified five market conditions where there were no significant differences between the disruption responses for the different permitted behaviours (market conditions 3, 7, 12, 14, and 22).

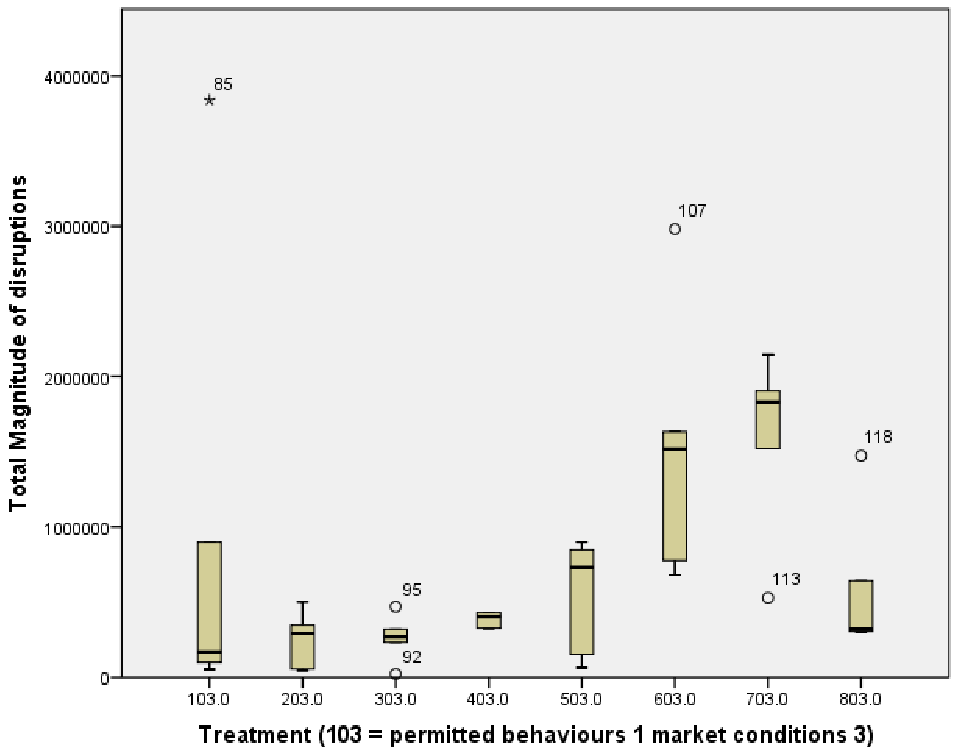


Figure 7—6: Experiment 2 total magnitude of diruptions market conditions 3

Examination of the boxplot in Figure 7—6 helps identify why no significant differences between the total magnitude of disruptions were detected. A number of outliers can be identified that draw the ranked means of the samples closer together. It would be inappropriate to remove these outliers; however, it is observable that if they did not exist then it is likely that significant differences between the samples are likely. Examination of the boxplots for market conditions 8, 12, 14 and 22 reveal similar characteristics.

Experiment 2 therefore supports the rejection of H3, establishing that permitted behaviour produces significant differences in disruption across all the market conditions considered in the experiment. In particular, the experiment illustrates that permitted behaviours of collaboration and price competition in open markets results in the highest levels of disruption.

Consideration of the cumulative distributions also highlights the nature of the disruptions in the context of the total disruptions experienced. That is to say how significant are the differences in disruption responses at different levels of magnitude? Are the differences a result of a few large or many small disruptions?

Figure 7—7 presents the cumulative distribution for the significantly different totals for market conditions 1, 9, 11, 15, 18, 19, and 24, all of which contrast with permitted behaviours 2 and 6. A number of observations can be made from this graph which helps to characterise the nature of disruptions. The first is that the permitted behaviours yielded between 3.25 and 13.5 days when disruptions exceeded between 25 and 50% of the total flows. The second is that the closed network didn't experience large disruptions because it tended to an equilibrium state in which the population was less than the initial population of suppliers. The third is that the proportion of days in which between 25 and 50% of the network material flows were rerouted ranged between 1 and 10%. Similar observations were made of the other market conditions where significant differences in total magnitude of disruptions were detected.

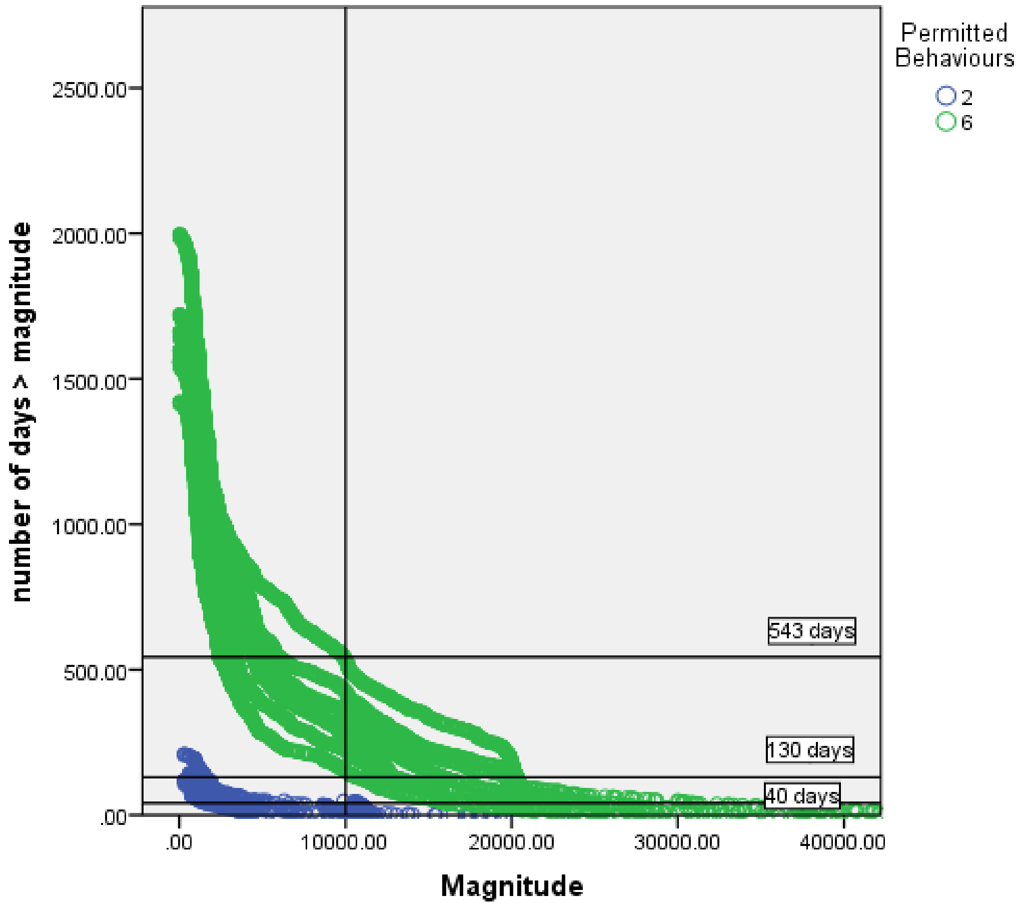


Figure 7—7: Cumulative distribution of disruptions comparing permitted behaviour blocks 2 and 6

Experiment 2 has highlighted significant differences in total magnitude of disruption across a number of contrasting permitted behaviours. Examination of the cumulative distribution of the disruptions for these contrasting cases highlights the difference between the permitted behaviours in the various market condition contexts.

7.6 Summary of Results

Table 7-6 summarises the results in the contexts of the research questions and the derived testable hypothesises.

Table 7-6: Summary of results

Research Question	**Hypothesis**	**Accepted/ Rejected**	**Comment**
Do supply networks comprising multiple connected supply chains experience periods of disruption as a consequence of normal operations?	H1: The pattern of cumulative distribution of disruptions experienced by a network under any of the permitted behaviours and market conditions conforms to an exponential law description	Accepted for open networks, rejected for closed networks	Open networks are critically organised and maintained in far from equilibrium states. As such they experience more disruptions of all magnitudes than closed networks Closed networks tend towards population equilibrium and experience fewer disruptions
What is the impact of market structure on the level of disruption experienced by networks?	H2: there is no difference in the magnitude of disruptions experienced by networks with different market conditions in any of the permitted agent behaviours combinations considered	Accepted	Market structure does not have any significant effect on the level of disruption experienced in any of the permitted behaviour configurations
What is the impact of price competition and collaboration between supply chain participants on the level of disruption experienced by the network?	H3: There is no significant difference between the magnitudes of disruptions experienced by networks with different permitted behaviour across all the considered market conditions.	Rejected	Permitted behaviour of collaboration and price competition results in significantly higher levels of disruption than alternative permitted behaviours in all the market conditions considered

7.6.1 Research Question 1

7.6.1.1 Observation 1

The generalised description of the results showed that supply networks of interconnected supply chains experience disruptions as a consequence of normal operations, the minimum considered scope of which was the agent's consideration of risk in the development of supply strategy in closed markets. Even at the minimal levels of permitted behaviours 25-50% of the network flows are being re-organised for 3% of the operational days.

7.6.1.2 Observation 2

The nature of the disruptions experienced by the network can be differentiated by closed and open markets. Closed markets tend towards an equilibrium state of organisation with steady populations of supply whilst open markets are maintained in a critical far from equilibrium state by the flows of suppliers into and out of the market.

7.6.2 Research question 2

7.6.2.1 Observation

No statistically significant difference was detected in the networks disruption response as a consequence of market conditions.

7.6.3 Research Question 3

7.6.3.1 Observation 1

Open markets experienced higher levels of total disruption than closed markets. Furthermore, they also experienced more frequent disruptions at all magnitudes of disruption.

7.6.3.2 Observation 2

Permitted behaviours of collaboration and price competition produced the highest total magnitude of disruption, although there was no significant difference in the descriptor of the cumulative distributions of disruptions. The inference of this last point is that whilst open systems can be described as critically organised, the nature of this organisation and the permitted behaviours cannot be differentiated by this characterisation.

7.7 Discussion

This thesis has used CAS theory as the foundation for conceptualising supply networks. The results of the experiments are significant in that they illustrate the difference between the more traditional supply chain conceptualisation and the broader more dynamic networks. The agents use a few simple rules to determine their actions:

1. Manage inventory by optimising the balance between uncertainty of demand and inventory holding
2. Establish a supply strategy that reflects the risk of supply
3. Select suppliers using five criteria, the importance of which is dependent on the utilisation of capacity and supply risk
4. Fulfil orders placed
5. Optimise capacity utilisation

These five rules are all drawn from existing theory and are validated by practice; in fact, many have been formulated using the more static conceptualisation of the supply chain. CAS theory has been used as a lens through which to view supply chains by a number of scholars (Bode et al., 2011; Choi et al., 2001a; Surana et al., 2005; Nair et al., 2009; Greening and Rutherford, 2011; 2011a; Allen et al., 2006). Although a few researchers have operationalised the fundamental aspects of autonomous supply chain management into agent based models there are notable exceptions (Nair and Vidal, 2011; Brintrup, 2010; Chang and Harrington, 2000; Allen et al., 2006). Furthermore, the combined impact of these autonomous management activities on the dynamics of the network have not previously been assessed in the context of disruptions.

Examination of the extant literature also reveals conceptualisations that accept critical organisation but understate the role openness plays in the conceptualisation of supply networks as CAS. For instance Choi et al.'s (2001a) seminal paper describing supply chains as CASs accepts that supply networks exist in far from equilibrium states but neglects the mechanism by which this is maintained. Prigogine (1997) recognised that the far from equilibrium state can only exist in open systems which provide a flow of resources into and out of the system.

Understanding complexity is difficult, as Pathak (2007a) reminds us in quoting Amaral and Uzzi (2007):

> *"In contrast to simple systems, such as the pendulum, which has a small number of well-understood components, or complicated systems, such as Boeing jet, which have many components that interact through predefined coordination rules (Perrow, 1999), complex systems typically have many components that can autonomously interact through emergent rules. In management contexts, complex systems arise whenever there are populations of interacting agents that can act on their limited and local information. The agents and the larger system in which they are embedded operate by trading their resources without the aid of a central control mechanism or even a clear understanding of how actions of (possibly distant) agents can affect them."*

Naturally extant knowledge provides the base from which new theory can make advances. In this context earlier work on supply networks as CASs provides the foundation for this research which seeks to advance the current theory by incorporating network openness as a means of generating criticality and understanding the phenomena of disruptions as a consequence of normal operations.

Whilst conceptually it is accepted that supply networks permit new entrants and the exiting of old, few models have been designed that reflect this aspect of complexity. Some models reflect death (e.g. (Nair and Vidal, 2011; Brintrup, 2010) but very few birth. This limited acceptance of a supply network tends to a population equilibrium and limits the extent to which the network can become critically organised. Furthermore, closed systems are not generally reflective of the supply network environment: it is the intent of all suppliers to displace incumbent suppliers for their own advantage. This research shows that when agents are allowed to exit the system (death) but are not replaced by new agents, then the system tends towards a state of population equilibrium and away from a critically organised state.

The fact that CASs are sensitive to initial conditions and are path dependent makes their understanding problematic. However, their critical organisation and other properties can be considered fundamental and characterise the system (Bak, 1999). Fundamental structures persist over a wide range of conditions and the analysis of the experimental data generated by this research shows that collaboration and price competition in open markets create significantly more disruptions in nearly all the market conditions evaluated. The openness of supply networks is therefore critical in allowing a new fundamental structure to start to emerge: collaboration and price competition in open markets resulting in significantly higher magnitudes of total disruption.

In identifying this structure some components of the mechanism that causes the phenomenon are exposed; in particular, the combination of price competition and collaboration. Whilst this thesis stops short of a detailed examination of how these components combine to develop disruptions logical arguments can be formed to explain the observations.

7.7.1 Price Competition and Collaboration

Collaboration requires commitment and trust between parties allowing organisations to design their interactions based on an assumption that both parties will preference the relationship above alternatives (Hunt and Morgan, 1994). Expressed differently, this amounts to increased inertia, a phenomenon that is established in the extant literature (Huxham and Vangen, 2004; Yanamandram and White, 2010). In contrast, competitive pricing is designed to disrupt relationships by displacing incumbent suppliers through increasing the attractiveness of the alternatives, and positions collaboration and competition as opposing forces. In this context it is possible to argue that competition dampens the inertia of collaborative relationships, yet the results of the experiments suggest otherwise with the combination of collaboration and price competition in open markets resulting in significantly higher magnitudes of disruption.

If collaboration could exist in isolation from price competition then supply networks would gravitate towards neo equilibrium. New entrants would find it difficult to displace existing suppliers without being permitted to increase their attractiveness through aggressive pricing. Instead, they would have to compete by increasing their attractiveness through the other supplier selection criteria, such as reliable delivery, shorter lead times, financial stability, or flexibility. All of these criteria are to some extent dependent on variables outside the control of the focal agent. Reliable delivery is a function of uncertainty in demand, which decreases with attractiveness. Shorter lead times is largely a function of location relative to the buying organisation, while financial stability is a consequence of attractiveness as well as a driver of it, and flexibility is a reflection of the willingness of an agent to collaborate. Of course organisations can take actions to improve the attractiveness of any of these variables but the effectiveness of these interventions is moderated by externalities, whereas price competition is directly controlled by the supplier and also impacts financial stability, and through third order effects dependency flexibility.

Collaboration distorts attractiveness by potentially maintaining buyer supplier relationships which are uncompetitive. Inflating the attractiveness of any supplier creates a feedback which increases the supplier's financial stability and reliability (as demand uncertainty is reduced by multiple buyers and shared demand information). This virtuous circle implies collaborating suppliers can become more attractive to the population as a whole.

The benefits of collaboration have particular potency in static environments, where competitors do not react and new entrants are not permitted. However, in open systems that permit competitive pricing, agents can (within the confines of market structures) discover strategies that overwhelm the attractiveness of collaboration. In such circumstances the incumbent supplier is constrained in its own response to challenge by its own well utilised capacity.

Successful collaborating suppliers can meet the challenge of new suppliers by investing in new capacity based on an assumption that they will remain attractive. This investment decision is cached in terms of balancing the commitment of existing buyers with the need to protect existing relationships by maintaining the existing character of the operation. This phenomenon has assumed the popular description of the ‘competency trap’. However, the nature of open markets ensures that there is a constant stream of competitors with business propositions that differentiate them from the incumbents; consequently, it is likely that eventually the incumbents succumb to the challenges and are usurped as suppliers. When incumbent suppliers are replaced the magnitude of the disruption depends on the how successful the incumbent supplier was: the more successful the previous supplier the bigger the magnitude of disruption when they are replaced.

This mechanism of inertia building a competency trap for the incumbent suppliers has received some attention in the academic literature and can be observed generally in the rise of the internet firm Amazon usurping traditional book shops, or the rise of electronically distributed music usurping compact discs and magnetic tapes.

This research made a simplifying assumption that agents would not be permitted to invest in extra capacity because the decisions to do so are complicated and drive the modelling process towards full economic models. However, the observations made suggest that if the model reflected the process of successful incumbent suppliers investing in extra capacity adequately, then the observed phenomenon may reduce in frequency but increase in magnitude, inferring that the findings remain robust.

The findings differentiate between closed and open markets suggesting that closed markets, whilst still experiencing disruptions, experience a much lower magnitude of disruptions. Closed markets represent high barriers to entry, and their tendency to consolidate into configurations that sustain equilibrium are characteristic of oligopolies or monopolies. In this respect the experiment’s comparison between open and closed markets is really a reflection of the open markets and monopolies/oligopolies (Williamson, 1991).

7.7.2 Initial Market Conditions

The research has also shown that the initial conditions of the network specified by a framework of market structure have no significant effect on the magnitude of disruptions. Discussion of this observation must start with an understanding of how the market conditions are used within the model and how this relates to the operations of supply chains.

Within the model market conditions do two things: 1) they specify the average price for each tier of the supply market; and 2) they specify the range within which the agents are permitted to modify their price.

The market conditions reflect the reality that products are manufactured from raw materials, the cost of which is reflected in the process of extracting the raw materials. The subsequent conversion of raw materials into products requires resources, which infers that the product can be offered to the market at a price that sustains the extraction, conversion and subsequent distribution. At each stage business are only sustainable if they generate surplus revenues or profits. By setting the average intake price (raw material price) and the selling price it is possible to set the prices for manufacturers and wholesalers (this was specified in section 6.1.4.1).

The agents modify their prices within the constraints set out by the market conditions in response to whether or not their capacity is under or over utilised. This establishes pricing as a dynamic within the model constrained by boundaries, and the inference of the observations is that the boundaries have no impact on model behaviour.

It is conceivable that when agents are provided with a large range within which to price their products they may never have to price at the boundaries. Alternatively, it may be the case that they quickly reach the limit of their permitted pricing resulting in no further changes until their context changes and they are motivated to modify their prices away from the current limit.

Unfortunately, the model did not collect data relating to the pricing adopted by the agents and therefore no data exists to prove or disprove the mechanisms described here. However, parameterisation of pricing across the tiers was considered by the author and the validating panel to be realistic in terms of the margins generated and the overlap permitted between tiers. Furthermore, it should be noted that agents who were permitted to change prices generated significantly higher magnitudes of total disruption than those that did not, thus inferring that permission to change prices impacted agent behaviour in terms of supplier selection and switching.

The most likely explanation is that any impact of market structure constraints on model behaviour is overwhelmed by the other dynamics contained in the model, and as a consequence, agents did not find the limits of pricing imposed on them to be restrictive resulting in no significant effect being detected. This represents a potential area of further work but is unlikely to detract from the findings regarding the impact of collaboration, and price competition in open markets.

7.7.3 Supply Chain Risk Management

The extant literature that considers supply chain disturbances as an endogenous risk generally advocates collaboration as a process that facilitates information sharing to sharpen the demand signal, reduce overall inventory, and increase responsiveness. However, there is very little literature that considers the impact of collaboration on what has generally been framed as exogenous risk.

This research suggests that whilst there are undoubted benefits in terms of collaboration sharpening the demand signal facilitating inventory reduction, there are a number of implicit assumptions that exclude consideration of the wider implications. The most substantial of these is that decisions made within the supply chain have no consequences outside it.

This research exposes a persistent paradox that whilst collaboration delivers beneficial reductions in inventory and increased responsiveness in the ‘business as usual’ context, it is also a significant factor in increasing risk associated with disruptions as opposed to disturbances.

In doing so the findings deliver a degree of predictability to a phenomenon that previously was unpredictable; if supply networks are open with price competition then collaboration significantly increases the risk of disruption. The increased levels of risk, when compared to traditional supply chain conceptualisations where supply strategy and collaboration are used as means by which supply risk is mitigated, are between 3 and 7 times greater when expressed as the number of days on which between 25 and 50% of the material flows are re-organised.

Several studies have highlighted how globalisation has increased the risk of disturbance in a supply chain (Bode et al., 2011; Greening and Rutherford, 2011; 2011a; Tapiero and Grando, 2008; Arnold et al., 2010a). Logically this is inevitable: lead times and extended geography increases order size which is amplified as the demand information flows up the supply chain in the form of orders creating amplified demand uncertainty (). At the same time businesses are pressurised to reduce inventory increasing the coupling of the supply network. These observations are supported by a number of surveys:

> *“[a] study of 138 global firms by the Aberdeen Group …….. found 99 per cent had been affected by at least one incident in their supply chain over the past 12 months. In addition, 58 per cent of the respondents said they had incurred financial losses as a result of the disruption.”*
>
> Aberdeen Group (2008)

> *“Over 70 per cent of organisations reported at least one supply chain disruption in 2012, with 39 per cent of disruption originating from a tier below the immediate supplier. “*
>
> BCI (2012)

> *“Efficient supply chain design works well when the environment is stable and predictable but the vulnerabilities are clearly on show when the environment becomes volatile and uncertain.”*
>
> CIPS CEO David Noble (2009) (2011)

If organisations are to operate in these liberal global markets it makes sense based on the analysis contained in this research to design risk mitigation strategies that reflect the systemic risk rooted in collaboration and competition. The design of these strategies is beyond the scope of this research; however, the findings suggest that successful strategies will undoubtedly have to embrace dynamism, critical organisation and emergence.

This will require the extension of current flexible/agile supply chain strategies to include proactive de-coupling triggered by heightened contextual awareness. Simulations of the type performed by this thesis may well provide industry with a new tool to map context and strategy in a virtual world. The ability to explore quickly emerging competitive landscapes will require refined sensing abilities and the technological capability to articulate these in simulations where the robustness of alternative strategies can be evaluated.

Kraljic’s (1983) portfolio approach to supply strategy still has tenancy in the world of supply networks. However, it may be viewed through the alternative lens of this research which places a subtly different emphasis on various aspects. For instance, Kraljic placed considerable emphasis on developing strategies that sought to increase the buyer’s power over the seller, which in many cases involves increasing the dependency of the supplier on the buyer. This research exposes the need to be cognisant of the impact of dependency on the dynamics of relationships and within the broader context of the supply network. Any strategy that increases the motivation for firms to collaborate in markets other than oligopolies and monopolies is likely to result in a significant increase in supply disruption, which Kraljic (1983) framed as supply risk. If Kraljic’s purchasing strategy framework is used naively then it entertains the possibility of generating a vicious circle, where deepening collaboration generates periodic episodes (punctuated equilibrium) of more supply disruption generating deeper collaboration.

This research suggests that the purchasing strategies developed by Kraljic (1983) should be coupled with a broader consideration of the supply risks those strategies may generate, situating purchasing strategy as a more dynamic process incorporated into the broader aspects of risk management and business continuity planning. The intelligent implementation of Kraljic's purchasing portfolio approach should include consideration of how dependency can be balanced with the ability of competitors to price aggressively. If Kraljic's (1983) portfolio approach to purchasing strategy is implemented naively then this research suggests that collaborative or high dependency strategies are likely to result in a network being vulnerable to disruptions.

The findings fundamentally modify the approaches to developing appropriate supply chain risk management strategies by identifying previously unknown risks associated with collaboration, requiring these to be balanced with the established benefits.

7.7.4 Normal Accident Theory

The empirical foundation of NAT is that of complex tightly coupled technology occasionally presenting novel unpredicted configurations, for which there is no contingency. These unpredictable events sometimes trigger human interventions, which because there is no prepared design can amplify the consequences of the original technological event generating more novel presentations and more interventions. In effect the systems become emergent and critically organised. It is not surprising therefore to find considerable overlap between CST and NAT. However, the complexity referred to in NAT is not agency based.

Supply networks are essentially tightly coupled complex social systems, similar to the technological systems described by NAT; however, they can be differentiated by the presence of agency, transforming them from complex systems into the more specific CASs. CASs require the lens of NAT to be modified to accept that problematic novel configurations can emerge in social, as well as technological systems. This extension of the NAT conceptualisation is made easier by the descriptions of interactions in terms of rules that behave as mechanisms, albeit with higher levels of uncertainty.

The research reveals that social supply networks experience episodes of disruption as a consequence of unpredictable presentations of agent system states, which aligns with Perrow's (1999) definition of tightly coupled complex systems and the frameworks of NAT as described in Chapter 2.

Even without adaptive capabilities supply networks exhibit the properties of a system that might experience normal accidents – tight coupling generated by inventory reduction strategies, shared modes, unfamiliar feedback loops, and multiple interactions. However, the introduction of agency only serves to increase complexity by blurring dependencies and redesigning relationships. Furthermore, the increased commitment associated with collaboration increases coupling, whilst price competition and openness increases the level of information to be processed resulting in increased complexity.

These research findings extend normal accident theory and apply its framework to the social aspects of adaptation in supply networks. In doing so the findings align with the agency–free framework already established by Perrow (1999) but also draws the framework towards HRO theory.

One question that emerges from the findings is:

> *If supply network disruptions are an inevitable consequence of complexity and coupling then what interventions can be taken to mitigate the risk of disruptions?*

The answer to this question lies beyond the immediate scope of this research; however, the financial imperative of inventory minimisation (inferring collaboration) precludes the obvious answer of de-coupling the network by increasing inventory buffers. In this context the first and third principles of HRO may have particular relevance in requiring organisations to have a preoccupation with the potential of disruption and to develop elevated levels of sensitivity in operations.

7.8 Summary

The results show that networks with permitted agent behaviours of collaboration and price competition in open markets experience significantly higher levels of disruptions than the networks with alternative permitted behaviours. Furthermore, open networks are shown to experience significantly greater magnitudes of disruption than closed networks.

The results also showed that market conditions did not have any significant effect on the level of disruptions experienced by the network in any of the market structures considered.

Finally, the results showed that closed networks tend to states of supply population equilibrium, whilst open networks are maintained in far from equilibrium states.

As the each experiment generated 1000 lines of data it is impractical to include the 1.2M lines of results, however a sample collection of data is provided in Appendix C

8 Conclusions and Further Work

This research is primarily motivated by observations of how disruptions flow along pathways that connect adjacent supply chains. When lightning struck the Phillips microchip plant in Albuquerque Ericsson's original supply chain disruptions were amplified by the actions of Nokia in the adjacent but connected supply chain. Although other cases were presented in chapter 1 this simple observation highlights two important characteristics: 1) connectivity allows disruptions and the consequential actions of others to flow across networks impacting multiple supply chains and 2) firms within supply networks act autonomously according to their perceptions of context and environment.

The significance of disruption is generally supported by various supply chain risk surveys such as the 2012 Business Continuity Institute's (2012):

> *"39% of analysed disruptions originated below the immediate tier 1 supplier, underscoring the second consecutive year the deep-rooted nature of disruption"*

Furthermore disruptions are not uncommon; in 2008 the Aberdeen group (2008) reported that:

> *" ….99 per cent [of firms surveyed] had been affected by at least one incident in their supply chain over the past 12 months* "

Chapter 1 set out the context of disruptions in detail; however It appears that despite practitioner awareness of how connectedness and complexity can combine to present significant supply chain risk, managers are still grappling with how best to mitigate that risk.

Chapter 2 set out the theories that underpin the supply network dynamic conceptualisation:

Two theoretical bases combine to provide a theoretical framework underpinning the phenomena described above: CAS theory and NAT.

CST identifies two important characteristics of complex systems relating to the process by which the system experiences episodes of significant reorganisation (punctuated equilibrium) (Bak, 1999). The first of these is critical organisation which can otherwise be described as sensitivity to conditions, small changes may or may not (dependent on the states of all the system components) result in unpredictable transitions to new levels of organization. The second characteristic is the fundamental mechanism of inertia, which is central to the generation of criticality (Bak, 1999) .

Both CST and NAT draw on complexity as a mechanism by which unique, unpredicted and un-designed configurations of the system are generated. However CST unpicks the mechanisms of transitions to expose inertia as a crucial component in the generation of re-organization/disruption.

CAS theory extends the framework of CST to incorporate autonomous adaptive agents and in doing so increases the complexity but becomes more representative of supply networks where firms act autonomously under conditions of bounded rationality to mitigate risk and maximise profit. This results in a structure that is constantly shifting as a consequence of autonomous actions.

By positioning supply networks within the CAS theoretical framework where organisations act to minimise inventory and increase coupling between suppliers and buyers, we are forced to ask whether the basic tenants of NAT still apply: do tight coupling and complexity combine in a fundamental structure that inevitably presents unique unpredictable configurations where coincident disturbances combine to generate disruptions as a consequence of nothing more than normal operations

Critical to this question is the understanding of what is meant by normal operations. This can be defined through examination of the extant literature describing supply chain management. 5 rules are drawn from the literature underpinned by theories of TCE and SET as an abstraction of the supply chain co-ordination of material flows across organisational boundaries. These rules also embrace the fundamental principle that firms compete to access limited resources in order to create advantage. The fundamental rules are:

- inventory management
- risk management
- maximise capacity utilisation
- fulfil orders
- and select suppliers

The operational framework of normal operations demonstrates how these rules accept an agents particular perception of supply risk to develop supply strategy, prioritise supplier selection criteria and manage relationships. Risk and risk perceptions are therefore a fundamental input into the mechanisms by which the dynamics of supply networks are generated and maintained. Furthermore risk provides an important input into the decision-making process regarding whether or not agents should choose to invest resources into developing trust and commitment to enable collaboration (Morgan and Hunt, 1994), which is recognised in the literature to develop relational inertia (Kim et al., 2006).

Of equal note amongst the cadre of supply chain management practices is that of inventory minimisation, not least because this increases the coupling between organisations whilst accelerating the flow of both information, material and therefore disruption. The consequences of inventory management are framed by NAT which posits that complexity removes traceability and coupling increases the likelihood of events coinciding to create bigger events or in the case of this thesis disruptions. This conceptualisation develops a crucial argument: the complexity of overlapping supply chains with multitudinous firms and connections disguises sources of disturbances which when coincident overwhelm the tightly coupled but economically efficient inventory buffers to become a disruption transmitted in a domino effect across the various network pathways.

The locating of supply networks and their dynamics in a frame of NAT and CAS theory sets the context for the overarching question posed in this research:

How do network structures evolve to develop or dissipate sources of network risk as a consequence of normal supply chain operations in the context of competing risk and competitive advantage seeking strategies?

Which has been alternatively framed as 3, more specific research questions, the first of which is:

Do supply networks comprising multiple connected supply chains experience periods of disruption as a consequence of normal operations?

Consideration of the role inertia plays in critical organization directs a reflection of whether or not inertia generating and inertia destroying behaviours of collaboration and price competition results in more or less disruptions, the resultant questions posed in the research were:

What is the impact of market structure on the level of disruption experienced by networks?

What is the impact of adaptation and collaboration between supply chain participants on the level of disruption experienced by the network?

One reason why normal accident theory may not have been commonly applied to the supply chain environment is that it is founded on complex technological systems, whilst considering human interventions in response to the emergence of unique unpredictable technology configurations as a key component to the escalation of disturbances in to disruptions or incidents in to catastrophes (Perrow, 1999).

It is in this context that we note supply chains and therefore supply networks of connected supply chains are essentially social systems where the components can not only reconfigure themselves as a system but also adapt as components within that system to redefine the systems capabilities (Choi et al., 2001a).

A consideration of the phenomena of normal accidents and punctuated equilibrium reveal the difficulty of collecting real world empirical data across extensive supply networks: timings of events are unpredictable and without notice of the conditions that may or may not generate supply disruptions data collection is difficult to organize.

In such circumstances Davis et al (2009) recommend the use of computer simulations using extant knowledge to specify the mechanisms, interactions and dynamics of a system in order that it can be exposed to rigorous experimental design not feasible in the real-world. If computer simulations are adopted as an approach it is imperative that the model is anchored in extant theory, validated by practitioners, and rigorously verified in its construction. These principles were adopted in the construction of the computer simulation resulting in a computerised abstraction of real world phenomena underpinned by extant theory and validated by practioners.

By incorporating the abstracted operational rules into simulated autonomous adaptive agents interactions can be established and an abstracted representation of the real world parameterised for experimentation. In line with both NAT and CAS theory the parameters selected reflect the two dimensions of the agent behaviour and market constraints.

A full 2 level full factorial design of 256 cases was specified which represented two levels of vertical market structure across 2 supply tiers, two levels of price diversity across 2 supply tiers, with permitted behaviours of collaboration and price competition expressed in isolation and combination in both open and closed markets.

The nuisance variables of location and initial pricing were controlled for each case by implementing repeated experiments seeded with different random number generators. In all 1280 simulations were carried out permitting statistical testing of the difference between cases to reject or accept the research questions.

The research questions were reformed into testable hypothesis in order that they could be statistically tested and significant differences between experimental cases exposed. The following section summarises the findings discussed in the previous chapter with relation to the research questions posed

8.1 Research Question 1**:**

> *Do supply networks comprising multiple connected supply chains experience periods of disruption as a consequence of normal operations?*
>
> *Hypotheses:: The pattern of cumulative distribution of disruptions experienced by a network under any of the permitted behaviours and market conditions conforms to an exponential law description*

The research found that all network configurations experienced levels of disruption as a consequence of normal operations. However the analysis of the data showed that whilst open systems demonstrated patterns of disruption that followed an exponential law description as a consequence of being critically organised and maintained in a far from equilibrium state, closed networks did not. The closed networks tend towards an equilibrium of supply population which resulted in patterns of disruption not conformant to descriptions of criticality.

The finding extends supply network knowledge by demonstrating that critical organisation can only be established in open but not closed networks. This partially supports the conceptualisation of supply networks presented by Choi (2001b) and Pathak (2007a), however it also highlights that closed networks are not critically organised and therefore not complex.

In establishing open networks as critically organised the research also places supply networks in the collection of systems considered by NAT.

The practical implications for the findings are:

Risk mitigation strategies for systemic risk in open networks should directly address inertia generating and inertia destroying activities

The emphasis on managing the risk associated with closed systems should be the mitigation of disturbances, which whilst not neglected in the management of open systems sits alongside increased emphasis on business continuity planning in open systems.

Business continuity planning should be cognisant that the adaptation of potential purchasing strategies across the network may increase the systemic risk and will therefore need to be balanced with appropriate supply strategy.

In the context of these implications to practice It is noted that the BCI 2012 survey stated:

> *"When considering the involvement of business continuity practioners in the procurement process, there is still a long way to go. 51% state d that business continuity featured as in integral part of the procurem ent process from the start, a modest improvement on 47% in 2011, but a significant minority either ignore business continuity or make it a post-purchase activity."*

8.2 Research question 2:

What is the impact of market structure on the level of disruption experienced by networks?

Hypothesis:: there is no difference in the magnitude of disruptions experienced by networks with different market conditions in any of the permitted agent behaviours combinations considered

Given a specified combination of permitted agent behaviours the findings show that market conditions did not have any significant effect on the level of disruption experienced by the network

CST and CAS are both premised with arguments that complex systems are sensitive to initial conditions. By allowing agents to generate their states by acting within specified boundaries (market conditions) the research resolves any ambiguity about how system or network level constraints impacts emergent system level behaviours.

In practical terms the regulation of market structure expressed as permitted pricing does not have any impact on network level disruption within the bounds of the experiments specified. The findings can therefore be useful in guiding the design of regulatory instruments.

8.3 Research question 3:

> *What is the impact of adaptation and collaboration between supply chain participants on the level of disruption experienced by the network?*
>
> *Hypothesis: There is no significant difference between the magnitudes of disruptions experienced by networks with different permitted behaviour across all the considered market conditions.*

The research found that combined permitted behaviours of collaboration and price competition in open markets generated significantly higher levels of disruption than behavioural configurations

This finding makes two contributions to theory: the first contribution supports the findings addressing the first research question as it confirms the conceptualisation of supply networks as complex adaptive systems is not appropriate to closed supply networks but is appropriate to open supply networks. The second contribution is that within open supply networks the combination of collaboration and price competition produces significantly more risk of disruptions than other combinations of permitted behaviours.

With regard to practice this finding presents managers with a paradox to be managed: in open markets collaboration strategies need to be balanced with risk mitigation when price competition is permitted and not regulated.

The disruption risk presented by open markets with collaboration and price competition is emergent and therefore lacks precise definition requiring managers to develop responsive capabilities using the principles contained in HRO theory (described in chapter 1).

Having directly addressed the three research questions it is desirable to return to the overarching question and express the findings in terms of how networks evolve to dissipate or concentrate disturbances resulting in disruptions.

The computer experiments carried out show combined behaviours of collaboration and price competition in open markets describes an environment where risk of disruptions is significantly greater than in in other behavioural configurations. This observation highlights how, in the context of supply disruptions, permitted behaviours are a key determinant of a supply networks evolution and its vulnerability to disruptions as a consequence of normal behaviour.

As a consequence of this research strategies to mitigate systemic disruption risk are directed to addressing the interaction between inertia generating and inertia destroying behaviours of collaboration and price competition in open markets.

8.4 Critique and further work

The motivation for this thesis was to address the gap in extant knowledge regarding the role of behaviours and structure generating systemic risks in emergent supply networks. By using the lenses of NAT and CAS to examine the complexity and coupling of a network the research has exposed fundamental structures that persist over a range of conditions providing a focus for the design of mitigating strategies.

By identifying the persistent relationship between the combination of collaboration with price competitive behaviour in open markets and the observed significantly higher levels of disruption, this thesis has advanced the understanding of how complexity develops disruption risk in supply networks.

As is the nature of theory development; critiques of theoretical advances illuminate new and previously unknown opportunities for future research.

The research exposes three areas of interests with regard to the topic of disruptions as a consequence of normal operations:1) network openness, 2) structural aspects of the network, and 3) agent behaviours.

8.4.1 Network Openness

The model described in this thesis prescribed a considered but nonetheless specific degree of openness: the rate at which new agents could enter the system testing the incumbents and their relationships.

In reality new firms are created based on often incomplete analysis of the existing market and the performance of the incumbents. Entry rates for new agents is therefore contingent on perceptions of market attractiveness. In turn market attractiveness is a reflection of the relationships established in the existing network.

Prigogine (Prigogine, 1997) identified openness as a crucial to the maintenance of far-from equilibrium states. Bak (1999) confirms critical organization as a characteristic of far from equilibrium states and Choi et al (Choi et al., 2001a) highlight the ability of a network to modify its environment by having fluid boundaries:

> *"One common way of changes in CASs occurs through altering the boundaries of the system. These boundaries change as a result of including or excluding particular agents and by adding or eliminating connections among agents, thereby changing the underlying patterns of interactions. "*

Despite this theoretical and conceptual anchoring of openness as a crucial component of complex behaviour, the operationalization of openness in supply networks is neglected in the extant literature.

Future research could use the frameworks of agency to determine market attractiveness to potential new entrants. The new entrants would establish the attractiveness of the market by considering existing firms' performance, and barriers to entry (e.g. regulation, investment and the power of incumbents) to decide whether or not to enter the market.

If market attractiveness could be operationalized relationships between it and levels of disruption could be established providing a refined understanding of how openness relates to the levels of disruption experienced.

8.4.2 Market structure

The findings that market structure constraints have no influence on the levels of disruption experienced would benefit from exposing the mechanisms that result in the observations. In particular studies regarding population configurations and their relationship with the constraints imposed would help reveal deeper understanding of why market structures/conditions have no significant effect on the level of disruptions as a consequence of normal operations

Research in this area could draw on population dynamics to describe the relationship between population characteristics and market structures.

The model also constrained the productive capacity of agents fixing it at a level determined by initial conditions. The effect of productive capacity on disruption was controlled for through randomisation and repeated experiments.

However it would be useful to understand the impact on disruption experience of relaxing capacity constraints and permitting successful agents to invest in extra capacity. This would test the logical argument that increasing capacity of successful agents attracts more customers to those agents thereby: increasing overall dependency on them; driving higher levels of collaboration within the network; and consequently developing higher levels of inertia.

This logical argument suggests that increasing capacity would reduce the frequency of disruptions but increase their magnitude resulting in higher levels of disruption over the network as a whole.

Alternatively a contra argument can be developed whereby increasing capacity increases attractiveness with the network tending towards monopoly or oligopoly of supply.

By resolving this question any research in this area would establish whether or not capacity constraints or the characterisation of dynamic capacity would result in more or less disruptions.

8.4.3 Behaviours

8.4.3.1 Competition and collaboration interaction

The research found that the combined effect of collaboration and cooperation in open markets resulted in significantly higher levels of disruption. The current model permitted agents to adopt these behaviours when conditions required them to do so. These conditions were described by perceptions of risk and underutilisation of capacity.

The model could be alternatively configured to collect data regarding the proportion of the population adopting collaborative strategies and price competition. Conceptually the acceptance of complex systems as recursive suggests that the system will exhibit critically in the relationships between population dynamics expressing combined behaviours of collaboration together with price competition and the levels of disruption experienced.

8.4.3.2 Operationalizing commitment and cooperation

For the purposes of the model considered in this thesis's the arbitrary setting of threshold levels of commitment and the calculation of commitment based on perceptions of supply risk have been adequate to address the research questions posed.

Qualitative studies of supply risk perception and commitment have exposed dependencies with factors that have been reflected in the construction of the model used in this research. However deeper understandings of how supply risk should be assessed and commitment levels established would enhance their operationalization in the modelling environment, allowing the model to be developed to evaluate alternative strategies and policies that might be considered as a consequence of this research.

8.4.4 Alignment of future work with existing research agendas

This chapter would not be complete without reference to the two dominant research agendas published in the extant literature. Choi et al (Choi et al., 2001a) identified 4 broad areas of research, of which this research addresses 2:

> "…. identify what types of catastrophe in SNs have occurred in the past and what were the processes through which they occurred?"

And

> *" SNs tend to behave in archetypal ways, depending on the macro-level structure that is present, the incentives driving individual suppliers, and the rules used for interaction. Therefore, another question might be, what are these archetypes and how do they change over time?"*

Pathak (2007a) provided a more defined research agenda organised into theoretical, methodological and technical themes. This research mainly addresses the theoretical the theoretical challenges identified, of the 11 identified this research addresses 5:

- Interfirm interactions affecting CASN topology
- Effect of environment on CASN evolution both at individual and system levels
- Decision making criteria at the firm, system, and environment levels that affect CASN evolution

- Policy design for CASN Notion of loose coupling among firms in a supply network
- Coevolution of supply chain strategy and supply network structure

This research set out to bridge a gap in the extant knowledge regarding how supply networks through their complexity and tight coupling generate disruptions as a consequence of normal operations. The research findings not only addressed the research questions directly by but also advanced the research agendas of other academics and as such makes the contribution to knowledge intended.

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APPENDICES

Appendix A Programme Code

Calculating_commitment_16a6

Model: Calculating_commitment_16a6

Description: this version of the model

- intialisation
- supplier selection
- inventory management

Initialisation - allocate approapriate values

Supplier Selection - make rational choices

Inventory Management - compiles

Next action: to consume inventory and generate orders CHECK THIS WORKS

CHECK ORDERMANAGEMENT

CHECK SELECT SUPPLIERS

CHECK HANDLING OF BADBOYS

retailers consume stock as programmed

?? check stock calcs

at time step [0] SS, ALT, SigmaD, ROP calulate OK

?? ordering - check order placed for EOQ or equivilent, when Stock+expected stock<ROP

all OK

??check order management works

receiving OK

creating replen OK

sending nsas OK

?? check cash flows

cash spent on delivery (covers distribution)

Cash received on delivery

?? what about operating costs

this version does away with Badboys and supplier management by executing select suppliers every tick and using quality in the supplier selection process

The quality [and other behavioural values] are re-assessed every 30 days which assumes am asynchronous profile over the poulation

Changed stock calcs lead time calc -max of suppliers not mean ==> no difference

General

Java Package Name calculating_commitment

File Name C:\Users\Philip\Documents\Thesis\Models\Calculating_commitment _16a6\Calculating_commitment_16a6.original.alp

Model Time

Model Time Units Day

Active Object Class: Main

Description: Read data file

allocate price and stock

allocate behavioural values

allocate market share to Retail outlets

General

Startup Code

```
database.modify("DELETE FROM Results");
try
{
//Read DataFile
Scanner fs = new Scanner(new FileInputStream
```

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```
("c:\\Users\\mn076059\\Documents\\Backup Sept 2010\\My
docs\\cranfield\\Thesis\\Model\\ThesisFinalVersion\\AgentPopConfi
```

```
g.txt"),"UTF-8");
TotalNoOfAgents=fs.nextInt();
noOfRetailers=fs.nextInt();
noOfWholesalers=fs.nextInt();
noOfManufacturers=fs.nextInt();
RetailMarketValue=fs.nextInt();
}catch(Exception e)
{
System.err.println(e);
}
// allocate Price and stock to agents
SettingInitialConditions();
for(int i=0; i<(noOfRetailers
+noOfWholesalers+noOfManufacturers); i++)
{
add_actor();
//actor.get(i).setXY(uniform()*500, uniform ()*500); //use global std
dev
actor.get(i).setXY(normal(.2,.8,.5,GlobalStdDev)*500,
normal(.2,.8,.5,GlobalStdDev)*500);
if (i<noOfRetailers)
{
actor.get(i).Retailer=1;
actor.get(i).Price= AvgRetailPrice + uniform ((RetailMinPriceAvgRetailPrice),
(RetailMaxPrice-AvgRetailPrice) ); //15+
(uniform(0,2)); //use global std dev
actor.get(i).Price=actor.get(i).Price;
//traceln ();
}
if (i>=(noOfRetailers) && i< (noOfRetailers+ noOfManufacturers))
{
actor.get(i).Manufacturer=1;
actor.get(i).Price= AvgManufacturerPrice +
(uniform((ManufacturerMinPriceAvgManufacturerPrice),(
ManufacturerMaxPriceAvgManufacturerPrice)));//
was3
actor.get(i).Price=actor.get(i).Price;
actor.get(i).Stock=100000;//(RetailMarketValue*14)/1.5;
}
if (i>=noOfRetailers+ noOfManufacturers)
{
actor.get(i).Wholesaler=1;
actor.get(i).Price=AvgWholesalePrice+
(uniform((WholesaleMinPriceAvgWholesalePrice),(
WholesaleMaxPrice-AvgWholesalePrice)));
//was8
actor.get(i).Price=actor.get(i).Price;
actor.get(i).Stock=100000;//RetailMarketValue*14/1.5;
}
}
traceln();
// allocate behaviours
for (int i=0;i<actor.size();i++)
{
//todo: should these be a normal distribution
//Random r= new Random (thisSeed); //this is a uniform distribution
to give the greatest variety
//double RandomNo=normal(.1,.5, r);
//double RandomNo=r.nextDouble();
/*double RandomNo=CollaborationSeed +uniform(-.1,.1); // not
required
if (RandomNo<.2) // this will load the low end values
```

```
{
RandomNo=.2;
}
if (RandomNo>.8)
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}*/
actor.get(i).Collaboration= .2 +normal(.6);
//actor.get(i).Learning=normal(.2,.8,.5,.1);
//actor.get(i).PricingApproach=normal(.2,.8,.5,.1);
actor.get(i).RiskAttitude=.2 +normal(.6);
actor.get(i).CostPrioritisation=normal(.2,.8,.5,.1);
actor.get(i).BuyingFSValue= normal(.2,.8,.5,.1);
actor.get(i).BuyingLocationValue= normal(.2,.8,.5,.1);
actor.get(i).BuyingPriceValue= normal(.2,.8,.5,.1);
actor.get(i).QualityValue=normal(.2,.8,.5,.1);
//thisSeed+=1;
}
//==================================================
==================================================
==================================
/*FindBiggestPriceDiffFunction();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Retailer>0)
{
actor.get(i).CalculatePriceDifferentiation();
}
}*/
// allocate market shares
MarketShareAllocation();
traceln();
for (int i=0;i<actor.size();i++)
{
actor.get(i).CreateSelectionIndexForSuppliers();
}
traceln();
CalculateDemandForSuppliers();
CalculateMinInitialCapacity();
for (int i=0;i<actor.size();i++)
{
SetOperationalCosts(actor.get(i));
SetHoldingCosts(actor.get(i));
}
//SettingOPerationalCosts();
CalculateDeliveryIndex();
CalculateMarginIndex();
traceln();
/*file.println ("ManufacturerPriceVariation" + " " +
ManufacturerPriceVariation + " " +
"ManufacturingMarginInput" + " " + ManufacturingMarginInput + " "
+
"MarketDifferentiation" + " " + MarketDifferentiation + " " +
"RetailPriceVariation" + " " + RetailPriceVariation + " " +
"WholesalePriceVariation" + " " + WholesalePriceVariation + " " +
WholesalerMaginInput + " ");*/
```

Advanced

```
Import import java.util.Scanner;
import java.io.*;
import Jama.*;
import flanagan.analysis.Regression;
```

```
import flanagan.analysis.RegressionFunction;
import flanagan.math.Polynomial;
import flanagan.io.*;
import java.io.Serializable;
import flanagan.complex.*;
//import flanagan.plot.*;
//import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
import javax.swing.JFrame;
//import edu.uci.ics.jung.graph.*;
```


Additional Code //using a comparator

```
public class MarketShareSortByScore implements
Comparator<MarketShareScores>{
public int compare (MarketShareScores Manufacturer1,
MarketShareScores Manufacturer2){
Double
Manufacturer1Score=Manufacturer1.TempMarketShareValue;
Double
Manufacturer2Score=Manufacturer2.TempMarketShareValue;
if (Manufacturer1Score>Manufacturer2Score){
return -1;
}else if (Manufacturer1Score<Manufacturer2Score){
return 1;
}else {
return 0;
}
}
}
//using a comparator
public class ActorScoresSortByPrice implements
Comparator<ActorPrice>{
public int compare (ActorPrice Manufacturer1, ActorPrice
Manufacturer2){
Double Manufacturer1Score=Manufacturer1.Price;
Double Manufacturer2Score=Manufacturer2.Price;
if (Manufacturer1Score>Manufacturer2Score){
return 1;
}else if (Manufacturer1Score<Manufacturer2Score){
return -1;
}else {
return 0;
}
}
}
//using a comparator
public class FSSortByFS1 implements
Comparator<SupplierFSScore>{
public int compare (SupplierFSScore Manufacturer1,
SupplierFSScore Manufacturer2){
Double Manufacturer1Score=Manufacturer1.SupplierFS;
Double Manufacturer2Score=Manufacturer2.SupplierFS;
if (Manufacturer1Score>Manufacturer2Score){
return -1;
}else if (Manufacturer1Score<Manufacturer2Score){
return 1;
}else {
return 0;
}
```

```
}
}
//using a comparator
public class SortRetailersByDemand implements
Comparator<ActorDemand>{
public int compare (ActorDemand Manufacturer1, ActorDemand
Manufacturer2){
Double Manufacturer1Score=Manufacturer1.BuyingDemand;
Double Manufacturer2Score=Manufacturer2.BuyingDemand;
if (Manufacturer1Score>Manufacturer2Score){
return -1;
}else if (Manufacturer1Score<Manufacturer2Score){
```
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```
return 1;
}else {
return 0;
}
}
}
//using a comparator
public class SortWholesalersByDemand implements
Comparator<ActorDemand>{
public int compare (ActorDemand Manufacturer1, ActorDemand
Manufacturer2){
Double Manufacturer1Score=Manufacturer1.BuyingDemand;
Double Manufacturer2Score=Manufacturer2.BuyingDemand;
if (Manufacturer1Score>Manufacturer2Score){
return -1;
}else if (Manufacturer1Score<Manufacturer2Score){
return 1;
}else {
return 0;
}
}
}
//using a comparator
public class SortRetailSuppliersByDemand implements
Comparator<ActorDemand>{
public int compare (ActorDemand Manufacturer1, ActorDemand
Manufacturer2){
Double Manufacturer1Score=Manufacturer1.SupplyDemand;
Double Manufacturer2Score=Manufacturer2.SupplyDemand;
if (Manufacturer1Score>Manufacturer2Score){
return 1;
}else if (Manufacturer1Score<Manufacturer2Score){
return -1;
}else {
return 0;
}
}
}
//using a comparator
public class SortRetailSuppliersByDemandMax implements
Comparator<ActorDemand>{
public int compare (ActorDemand Manufacturer1, ActorDemand
Manufacturer2){
Double Manufacturer1Score=Manufacturer1.SupplyDemand;
Double Manufacturer2Score=Manufacturer2.SupplyDemand;
if (Manufacturer1Score>Manufacturer2Score){
return -1;
```

```
}else if (Manufacturer1Score<Manufacturer2Score){
return 1;
}else {
return 0;
}
}
}
//using a comparator
public class SortWholesaleSuppliersByDemand implements
Comparator<ActorDemand>{
public int compare (ActorDemand Manufacturer1, ActorDemand
Manufacturer2){
```



```
Double Manufacturer1Score=Manufacturer1.SupplyDemand;
Double Manufacturer2Score=Manufacturer2.SupplyDemand;
if (Manufacturer1Score>Manufacturer2Score){
return 1;
}else if (Manufacturer1Score<Manufacturer2Score){
return -1;
}else {
return 0;
}
}
}
//using a comparator
public class SortWholesaleSuppliersByDemandMax implements
Comparator<ActorDemand>{
public int compare (ActorDemand Manufacturer1, ActorDemand
Manufacturer2){
Double Manufacturer1Score=Manufacturer1.SupplyDemand;
Double Manufacturer2Score=Manufacturer2.SupplyDemand;
if (Manufacturer1Score>Manufacturer2Score){
return -1;
}else if (Manufacturer1Score<Manufacturer2Score){
return 1;
}else {
return 0;
}
}
}
//ActorSelectionValues
//MyValues
//using a comparator
public class SortActorSelectionValuesBySD implements
Comparator<MyValues>{
public int compare (MyValues Manufacturer1, MyValues
Manufacturer2){
Double Manufacturer1Score=Manufacturer1.SDDemand;
Double Manufacturer2Score=Manufacturer2.SDDemand;
if (Manufacturer1Score>Manufacturer2Score){
return -1;
}else if (Manufacturer1Score<Manufacturer2Score){
return 1;
}else {
return 0;
}
}
}
//using a comparator
public class SortRetailersDS implements
```

```
Comparator<DeliveryStuff>{
public int compare (DeliveryStuff Manufacturer1, DeliveryStuff
Manufacturer2){
Double Manufacturer1Score=Manufacturer1.SigmaDemand;
Double Manufacturer2Score=Manufacturer2.SigmaDemand;
if (Manufacturer1Score>Manufacturer2Score){
return -1;
}else if (Manufacturer1Score<Manufacturer2Score){
return 1;
}else {
return 0;
}
}
```



```
}
//using a comparator
public class SortActorsByMargin implements
Comparator<MarginStuff>{
public int compare (MarginStuff Manufacturer1, MarginStuff
Manufacturer2){
Double Manufacturer1Score=Manufacturer1.Margin;
Double Manufacturer2Score=Manufacturer2.Margin;
if (Manufacturer1Score>Manufacturer2Score){
return -1;
}else if (Manufacturer1Score<Manufacturer2Score){
return 1;
}else {
return 0;
}
}
}
```

Auto-create Datasets true

Recurrence 1

Dataset Samples To Keep 100

Parameter: MarketDifferentiation

General

Show At Runtime false

Type double

Default Value .2

Editor

Editor Control TEXT_BOX

Parameter: RetailPriceVariation

General

Show At Runtime false

Type double

Default Value .2

Editor

Editor Control TEXT_BOX

Parameter: WholesalePriceVariation

General

Show At Runtime false

Type double

Default Value .2

Editor

Editor Control TEXT_BOX

Parameter: ManufacturerPriceVariation

General

Show At Runtime false

Type double

Default Value .2

Editor

Editor Control TEXT_BOX

Parameter: ManufacturingMarginInput

General

Show At Runtime false

Type double

Default Value .5

Editor

Editor Control TEXT_BOX

Parameter: WholesalerMaginInput

General

Show At Runtime false

Type double

Default Value .3

Editor

Editor Control TEXT_BOX

Dynamic Event: Createnewmanufacturer

General

Show At Runtime false

Action
```
//int thisSeed=CollaborationSeed;
//Random r= new Random (thisSeed);
//double RandomNo=r.nextDouble();
//double RandomNo=CollaborationSeed +uniform(-.05,.05);
double ActorType1=3;
double
AverageOperatingCosts=SetOPerationalCostsForNewBorns(ActorT
ype1);
double NewnoOfManufacturers=0;
add_actor();
int k=actor.size()-1;
actor.get(k).Manufacturer=1;
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).Manufacturer>0)
{
NewnoOfManufacturers+=1;
}
}
k= actor.size()-1;
actor.get(k).OperatingCosts= AverageOperatingCosts;
actor.get(k).Cash=40*actor.get(k).OperatingCosts;
if (Double.isNaN(actor.get(k).Cash))
{
traceln();
}
```

```
actor.get(k).MySizeAndType.setFillColor(blue);
//actor.get(k).setXY(uniform()*500, uniform ()*500);
actor.get(k).setXY(normal(.2,.8,.5,GlobalStdDev)*500,
normal(.2,.8,.5,GlobalStdDev)*500);
actor.get(k).Price=AvgManufacturerPrice +
(uniform((ManufacturerMinPriceAvgManufacturerPrice),(
ManufacturerMaxPriceAvgManufacturerPrice)));
actor.get(k).Stock=7*RetailMarketValue/NewnoOfManufacturers;
//thisSeed=CollaborationSeed;
actor.get(k).JustBorn=1;
// r= new Random (thisSeed);
//todo: should these be a normal distribution
//Random r= new Random (thisSeed); //this is a uniform distribution
to give the greatest variety
//double RandomNo=normal(.1,.5, r);
// RandomNo=r.nextDouble();
//double RandomNo=CollaborationSeed +uniform(-.5,.05);
/*if (RandomNo<.2) // this will load the low end values
{
RandomNo=.2;
}
if (RandomNo>.8)
{
RandomNo=.8;
}*/
actor.get(k).Collaboration= normal(.2,.8,.5,.1);
//actor.get(i).Learning=normal(.2,.8,.5,.1);
//actor.get(i).PricingApproach=normal(.2,.8,.5,.1);
actor.get(k).RiskAttitude=normal(.2,.8,.5,.1);
actor.get(k).CostPrioritisation=normal(.2,.8,.5,.1);
actor.get(k).BuyingFSValue= normal(.2,.8,.5,.1);
actor.get(k).BuyingLocationValue= normal(.2,.8,.5,.1);
actor.get(k).BuyingPriceValue= normal(.2,.8,.5,.1);
actor.get(k).QualityValue=normal(.2,.8,.5,.1);
AverageOperatingCosts=0;
```

Dynamic Event: Createnewretailer

General

Show At Runtime false

Action double ActorType1=1;

```
double
AverageOperatingCosts=SetOPerationalCostsForNewBorns(ActorT
ype1);
add_actor();
int k=actor.size()-1;
actor.get(k).OperatingCosts= AverageOperatingCosts;
//actor.get(k).setXY(uniform()*500, uniform ()*500);
actor.get(k).setXY(normal(.2,.8,.5,GlobalStdDev)*500,
normal(.2,.8,.5,GlobalStdDev)*500);
actor.get(k).Retailer=1;
actor.get(k).Cash=14*actor.get(k).OperatingCosts;
if (Double.isNaN(actor.get(k).Cash))
{
traceln();
}
actor.get(k).Price=AvgRetailPrice + uniform ((RetailMinPriceAvgRetailPrice),
(RetailMaxPrice-AvgRetailPrice) ); //15+
(uniform(0,2));
actor.get(k).MySizeAndType.setFillColor(red);
```

```
actor.get(k).JustBorn=1;
//int thisSeed=CollaborationSeed;
///Random r= new Random (thisSeed);
//todo: should these be a normal distribution
//Random r= new Random (thisSeed); //this is a uniform distribution
to give the greatest variety
//double RandomNo=normal(.1,.5, r);
//double RandomNo=r.nextDouble();
/*double RandomNo=CollaborationSeed +uniform(-.05,.05);
if (RandomNo<.2) // this will load the low end values
{
RandomNo=.2;
}
if (RandomNo>.8)
{
RandomNo=.8;
}*/
//actor.get(i).Collaboration= normal(.2,.8,.5,.1);
//actor.get(i).Learning=normal(.2,.8,.5,.1);
//actor.get(i).PricingApproach=normal(.2,.8,.5,.1);
actor.get(k).RiskAttitude=normal(.2,.8,.5,.1);
actor.get(k).CostPrioritisation=normal(.2,.8,.5,.1);
actor.get(k).BuyingFSValue= normal(.2,.8,.5,.1);
actor.get(k).BuyingLocationValue= normal(.2,.8,.5,.1);
actor.get(k).BuyingPriceValue= normal(.2,.8,.5,.1);
actor.get(k).QualityValue=normal(.2,.8,.5,.1);
//thisSeed+=1;
AverageOperatingCosts=0;
```

Dynamic Event: Createnewwholesaler

General

Show At Runtime false

```
Action //int thisSeed=CollaborationSeed;
//Random r= new Random (thisSeed);
//double RandomNo=r.nextDouble();
//double RandomNo=CollaborationSeed +uniform(-.05,.05);
double ActorType1=2;
double
AverageOperatingCosts=SetOPerationalCostsForNewBorns(ActorT
ype1);
double NewnoOfWholesalers=0;
add_actor();
```

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```
int k=actor.size()-1;
actor.get(k).Wholesaler=1;
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).Wholesaler>0)
{
NewnoOfWholesalers+=1;
}
}
if (NewnoOfWholesalers==0)
{
traceln();
}
actor.get(k).Stock=7*RetailMarketValue/NewnoOfWholesalers;
if (k==14)
{
```

```
traceln();
}
if (Double.isNaN(actor.get(k).Stock))
{
traceln();
}
actor.get(k).OperatingCosts= AverageOperatingCosts;
actor.get(k).Cash=40*actor.get(k).OperatingCosts;
if (Double.isNaN(actor.get(k).Cash))
{
traceln();
}
actor.get(k).MySizeAndType.setFillColor(yellow);
//actor.get(k).setXY(uniform()*500, uniform ()*500);
actor.get(k).setXY(normal(.2,.8,.5,GlobalStdDev)*500,
normal(.2,.8,.5,GlobalStdDev)*500);
actor.get(k).Wholesaler=1;
actor.get(k).Price=AvgWholesalePrice+
(uniform((WholesaleMinPriceAvgWholesalePrice),(
WholesaleMaxPrice-AvgWholesalePrice)));
//=======
actor.get(k).JustBorn=1;
//thisSeed=CollaborationSeed;
// r= new Random (thisSeed);
//todo: should these be a normal distribution
//Random r= new Random (thisSeed); //this is a uniform distribution
to give the greatest variety
//double RandomNo=normal(.1,.5, r);
//RandomNo=r.nextDouble();
//double RandomNo=CollaborationSeed +uniform(-.5,.05);
/*if (RandomNo<.2) // this will load the low end values
{
RandomNo=.2;
}
if (RandomNo>.8)
{
RandomNo=.8;
}*/
actor.get(k).Collaboration= normal(.2,.8,.5,.1);
//actor.get(i).Learning=normal(.2,.8,.5,.1);
//actor.get(i).PricingApproach=normal(.2,.8,.5,.1);
actor.get(k).RiskAttitude=normal(.2,.8,.5,.1);
actor.get(k).CostPrioritisation=normal(.2,.8,.5,.1);
actor.get(k).BuyingFSValue= normal(.2,.8,.5,.1);
actor.get(k).BuyingLocationValue= normal(.2,.8,.5,.1);
actor.get(k).BuyingPriceValue= normal(.2,.8,.5,.1);
actor.get(k).QualityValue=normal(.2,.8,.5,.1);
//thisSeed+=1;
AverageOperatingCosts=0;
if (Double.isNaN(actor.get(k).Stock))
{
traceln();
}
traceln();
```


Calculating_commitment_16a6

Function: CalculatingCommitment

General

Show At Runtime false

Return Type double

Code

Body return

```
(pow((GlobalRisk*RelationalRisk*EuclideanDistance),.3333));
```

Arguments:

Name Type

GlobalRisk double

RelationalRisk double

EuclideanDistance double

Function: CalculateED

General

Show At Runtime false

Return Type void

Function: CalculateCurrentNetworkRisk

General

Show At Runtime false

Return Type void

Function: MarketShareAllocation

Description: This algorithm assumes that even the smallest difference in price will result in substantial market share difference

General

Show At Runtime false

Return Type void

Code

Body

```
//int population=10;
ActorsRanked.clear();
//rank retailers according to their price
if (actor.size()==11)
{
traceln();
}
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Retailer>0 && actor.get(i).Died<1)
{
ActorPrice thisActorPrice=new
ActorPrice(actor.get(i),actor.get(i).Price);
ActorsRanked.add(thisActorPrice);
}
}
//sort
```

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```
Collections.sort(ActorsRanked,new ActorScoresSortByPrice());
//Allocate Market share
for (int i=0;i<ActorsRanked.size();i++)
{
ActorsRanked.get(i).Actor.TargetMarketShare=0;
}
double marketsharetotal=100;
if (time()==0)
{
while (marketsharetotal>0.1)
{
for (int i=0;i<ActorsRanked.size();i++)
{
ActorsRanked.get(i).Actor.TargetMarketShare +=
```

```
(MarketDifferentiation*marketsharetotal)/100;
marketsharetotal=marketsharetotal(
MarketDifferentiation*marketsharetotal);
//ActorsRanked.get(i).Actor.CurrentDemand=
((ActorsRanked.get(i).Actor.TargetMarketShare/100)*RetailMarketV
alue) + (normal(0,.2)*
//(ActorsRanked.get(i).Actor.TargetMarketShare/100)*RetailMarket
Value);
//ActorsRanked.get(i).Actor.Stock= uniform(1.5,2)
*ActorsRanked.get(i).Actor.CurrentDemand*14;
//ActorsRanked.get(i).Actor.SigmaDemand=uniform(.03,.05)*(Actor
sRanked.get(i).Actor.CurrentDemand);
//ActorsRanked.get(i).Actor.BaseOPerationalDemand=ActorsRanke
d.get(i).Actor.CurrentDemand;
//SetOperationalCosts(ActorsRanked.get(i).Actor);
//ActorsRanked.get(i).Actor.OperatingCosts=.2*
ActorsRanked.get(i).Actor.BaseOPerationalDemand *
ActorsRanked.get(i).Actor.Price;
//ActorsRanked.get(i).Actor.OPeratingCostsPerUnit=ActorsRanked.
get(i).Actor.OperatingCosts/ActorsRanked.get(i).Actor.BaseOPerati
onalDemand;
}
traceln();
}
//all market share allocated
for (int i=0;i<ActorsRanked.size();i++)
{
ActorsRanked.get(i).Actor.CurrentDemand=ActorsRanked.get(i).Act
or.TargetMarketShare*RetailMarketValue;
ActorsRanked.get(i).Actor.SigmaDemand=uniform(.03,.05)*(Actors
Ranked.get(i).Actor.CurrentDemand);
ActorsRanked.get(i).Actor.Stock= uniform(1.5,2)
*ActorsRanked.get(i).Actor.CurrentDemand*14;
ActorsRanked.get(i).Actor.BaseOPerationalDemand=ActorsRanked
.get(i).Actor.CurrentDemand;
SetOperationalCosts(ActorsRanked.get(i).Actor);
}
//now allocate current demand, base op demand, op costs,
}
traceln();
if(time()>0)
{
while (marketsharetotal>0.1)
{
for (int i=0;i<ActorsRanked.size();i++)
{
```



```
Actor.TargetMarketShare*RetailMarketValue;
ActorsRanked.get(i).Actor.SigmaDemand=uniform(.03,.05)*(Actors
Ranked.get(i).Actor.CurrentDemand);
ActorsRanked.get(i).Actor.CurrentDemand=
(normal(ActorsRanked.get(i).Actor.SigmaDemand,ActorsRanked.ge
t(i).Actor.CurrentDemand));
//ActorsRanked.get(i).Actor.BaseOPerationalDemand=ActorsRanke
d.get(i).Actor.CurrentDemand;//!!!!!!!!!!!!
//SetOperationalCosts(ActorsRanked.get(i).Actor);//!!!!!!!!!!!!!!!!!!!!!!!!!
//make it normal dist
if (ActorsRanked.get(i).Actor.JustBorn>0)
{
//ActorsRanked.get(i).Actor.BaseOPerationalDemand=ActorsRanke
```

```
d.get(i).Actor.CurrentDemand;
ActorsRanked.get(i).Actor.Stock= uniform(1.5,2)
*ActorsRanked.get(i).Actor.CurrentDemand*14;
ActorsRanked.get(i).Actor.JustBorn=0;
}
if (i==10)
{
traceln();
}
}
}
}
traceln();
```

Function: CalculateGlobalRisk

Description: calculates global risk by comparing actual links to ideal

REQUIRED

CALCULATE ACTUAL COV AND COMAPRE TO IDEAL ==> GLOBAL RISK

General

Show At Runtime false

Return Type void

Code

Body

```
//sets CurrentIdealDemand=0
for (int i=0;i<actor.size();i++)
{
actor.get(i).CurrentIdealDemand=0;
}
SortRetailersByDemand();
SortRetailSuppliersByDemand();
//WholesaleSuppliersSortedByDemand.clear();
/*for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Manufacturer>0)
{
actor.get(i).CurrentIdealDemand=0;
}
}*/
//for each retailer
if (RetailersSortedByDemand.size()>0 &&
RetailSuppliersSortedByDemand.size()>0 )
{
```



```
for (int i=0;i<RetailersSortedByDemand.size();i++)
{
RetailSuppliersSortedByDemand.get(0).SupplyDemand+=Retailers
SortedByDemand.get(i).BuyingDemand/2;
Collections.sort(RetailSuppliersSortedByDemand,new
SortRetailSuppliersByDemand());
RetailSuppliersSortedByDemand.get(0).SupplyDemand+=Retailers
SortedByDemand.get(i).BuyingDemand/2;
Collections.sort(RetailSuppliersSortedByDemand,new
SortRetailSuppliersByDemand());
}
}
traceln();
if (RetailSuppliersSortedByDemand.size()>0)
{
for (int i=0;i<RetailSuppliersSortedByDemand.size();i++)
```

```
{
RetailSuppliersSortedByDemand.get(i).Actor.CurrentIdealDemand=
RetailSuppliersSortedByDemand.get(i).SupplyDemand;
}
}
//now do the same for wholesalers to manufacturers
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Wholesaler>0 && actor.get(i).Died<1)
{
ActorDemand thisActorDemand=new
ActorDemand(actor.get(i),actor.get(i).CurrentIdealDemand,0 );
WholesalersSortedByDemand.add(thisActorDemand);
}
}
traceln();
Collections.sort(WholesalersSortedByDemand,new
SortWholesalersByDemand());
traceln();
//add wholesale suppliers to collection
WholesaleSuppliersSortedByDemand.clear();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Manufacturer>0 && actor.get(i).Died<1)
{
ActorDemand thisActorDemand=new
ActorDemand(actor.get(i),0,actor.get(i).CurrentIdealDemand );
WholesaleSuppliersSortedByDemand.add(thisActorDemand);
}
}
traceln();
Collections.sort(WholesaleSuppliersSortedByDemand,new
SortWholesalersByDemand());
traceln();
if (WholesalersSortedByDemand.size()>0 &&
WholesaleSuppliersSortedByDemand.size()>0 )
{
for (int i=0;i<WholesalersSortedByDemand.size();i++)
{
WholesaleSuppliersSortedByDemand.get(0).SupplyDemand+=Who
lesalersSortedByDemand.get(i).BuyingDemand/2;
Collections.sort(WholesaleSuppliersSortedByDemand,new
```



```
SortWholesaleSuppliersByDemand());
WholesaleSuppliersSortedByDemand.get(0).SupplyDemand+=Who
lesalersSortedByDemand.get(i).BuyingDemand/2;
Collections.sort(WholesaleSuppliersSortedByDemand,new
SortWholesaleSuppliersByDemand());
}
}
traceln();
if (WholesaleSuppliersSortedByDemand.size()>0)
{
for (int i=0;i<WholesaleSuppliersSortedByDemand.size();i++)
{
WholesaleSuppliersSortedByDemand.get(i).Actor.CurrentIdealDem
and+=WholesaleSuppliersSortedByDemand.get(i).SupplyDemand;
}
}
traceln();
```

```
if (time()==2)
{
traceln();
}
WholesalersSortedByDemand.clear();
// todo: calculate COV ==> where to put this ==> not entire network
but partitioned according type !!!!!!!!!!!!!!!!!!!!!!!!!
CovDataSet.reset();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && (actor.get(i).Wholesaler>0 ||
actor.get(i).Manufacturer>0))
{
CovDataSet.add(actor.get(i).CurrentIdealDemand);
}
}
if (CovDataSet.count()>0)
{
COVidealRetailerSuppliers=CovDataSet.deviation()/CovDataSet.m
ean();
}
// calculate max imum value
/*double sum=0;
//double MaxCOV=0
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).Retailer>0 )
{
sum+=actor.get(i).CurrentDemand;
}
}
//count no of suppliers
double count=0;
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && (actor.get(i).Wholesaler >0 ||
actor.get(i).Manufacturer >0 ))
{
count+=1;
}
}
//allocate supply
double flag=0;
double MinRetailerDemand=CalculateMinimumRetailerDemand();
if (count>2) //!!!!!!!!!!!! WHAT HAPPENS IF JUST 1 SUPPLIER
!!!!!!!!!!!!!!!!!! OR 2 SUPPLIERS
{
flag=1;
```


```
}
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && (actor.get(i).Wholesaler >0 ||
actor.get(i).Manufacturer >0 ))
{
if (flag==1)
{
//add sum-count-1
MaxCov.add (sum-(MinRetailerDemand/2)); // INSTEAD OF 1 THIS
SHOULD PROBABLY BE THE MNIMUM RETAILER CUSTOMER
```

```
DEMAND
MaxCov.add (MinRetailerDemand/2);
}
else
{
MaxCov.add(sum);
}
}
}*/
//MaxCov.add(1);
//MaxCov.add(sum-1);
//MaxTheoreticalCOV=
MaxGlobalRiskCalculatation();//MaxCov.deviation()/MaxCov.mean()
; //NEEDS TO BE CORRECTED FOR THE RANGE
MaxCov.reset();
```

Function: CalculateDemandForSuppliers

General

Show At Runtime false

Return Type void

Code

```
Body traceln();
/*for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).MySuppliers.size()>0
&& (actor.get(i).Retailer==1 || actor.get(i).Wholesaler==1))
{
traceln();
actor.get(i).CurrentDemand=0;
for (int j=0;j<actor.get(i).MySuppliers.size();j++)
{
actor.get(i).MySuppliers.get(j).CurrentDemand+=actor.get(i).Curren
tDemand/actor.get(i).MySuppliers.size();
}
}
}*/
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Wholesaler>0 || actor.get(i).Manufacturer>0)
{
actor.get(i).CurrentDemand=0;
}
}
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Retailer>0)
{
```



```
{
if (actor.get(j).Wholesaler>0 &&
actor.get(i).MySuppliers.contains(actor.get(j)))
{
actor.get(j).CurrentDemand+=actor.get(i).CurrentDemand/((double)
actor.get(i).MySuppliers.size());
}
}
}
}
for (int i=0;i<actor.size();i++)
```

```
{
if (actor.get(i).Manufacturer>0)
{
for (int j=0;j<actor.size();j++)
{
if ( actor.get(j).MySuppliers.contains(actor.get(i)))
{
actor.get(i).CurrentDemand+=actor.get(j).CurrentDemand/((double)
actor.get(j).MySuppliers.size());
}
}
```

Function: AllocateDemand

General

Show At Runtime false

Return Type void

Function: AllocateOptimalDemandToWholesalers

General

Show At Runtime false

Return Type void

Code

Body

```
for (int i=0;i<RetailSuppliersSortedByDemand.size();i++)
{
if (RetailSuppliersSortedByDemand.get(i).Actor.Wholesaler>0 &&
RetailSuppliersSortedByDemand.get(i).Actor.Died<1)
{
RetailSuppliersSortedByDemand.get(i).Actor.CurrentIdealDemand=
RetailSuppliersSortedByDemand.get(i).SupplyDemand;
}
}
traceln();
```

Function: AllocateOptimalDemandToManufacturers

General

Show At Runtime false

Return Type void

Code

Body for (int i=0;i<RetailSuppliersSortedByDemand.size();i++)

```
{
if (RetailSuppliersSortedByDemand.get(i).Actor.Manufacturer>0 &&
```



```
RetailSuppliersSortedByDemand.get(i).Actor.Died<1)
{
RetailSuppliersSortedByDemand.get(i).Actor.CurrentIdealDemand=
RetailSuppliersSortedByDemand.get(i).SupplyDemand;
}
}
traceln();
```

Function: SortRetailersByDemand

General

Show At Runtime false

Return Type void

Code

Body

```
RetailersSortedByDemand.clear();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Retailer>0 && actor.get(i).Died<1)
{
ActorDemand thisActorDemand=new
ActorDemand(actor.get(i),actor.get(i).CurrentDemand,0 );
RetailersSortedByDemand.add(thisActorDemand);
}
}
Collections.sort(RetailersSortedByDemand,new
SortRetailersByDemand());
```

Function: SortRetailSuppliersByDemand

General

Show At Runtime false

Return Type void

Code

```
Body RetailSuppliersSortedByDemand.clear();
if (time()==1)
{
traceln();
}
for (int i=0;i<actor.size();i++)
{
if ((actor.get(i).Wholesaler>0 || actor.get(i).Manufacturer>0) &&
actor.get(i).Died<1)
{
//todo: calculate demand - by checking whether or not this actor has
been selected, and summing the current demnd
//sort retail suppliers by allocated demand (supply demand)
ActorDemand thisActorDemand=new ActorDemand(actor.get(i),0,
actor.get(i).CurrentIdealDemand);
RetailSuppliersSortedByDemand.add(thisActorDemand);
}
```



```
}
//todo: sort collection RetailersSortedByDemand
Collections.sort(RetailSuppliersSortedByDemand,new
SortRetailSuppliersByDemand());
traceln();
```

Function: SortWholesalersByDemand

General

Show At Runtime false

Return Type void

Code

```
Body WholesalersSortedByDemand.clear();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Wholesaler>0 && actor.get(i).Died<1)
{
ActorDemand thisActorDemand=new
ActorDemand(actor.get(i),actor.get(i).CurrentDemand,0 );
WholesalersSortedByDemand.add(thisActorDemand);
}
}
// need method to sort wholsalers by demand
```

Collections.sort(WholesalersSortedByDemand,new
SortWholesalersByDemand());

Function: CalculateBuyingLocationValue

Description: Calculates the delivery value/weight for retailers and wholesalers

General

Show At Runtime false

Return Type void

Code

Body //this needs to be a function of SD ==> the greater the SD demand
the greate the value of BuyingLocationVlaue
// as the SD demand can assume any value it needs to be indexed
amongst the agents peers
/*public Actor ThisActor;
COULD WE ADD TYPE
public double SDDemand;
public double SDDemandValue;
public double FS;
public double FSValue;
public double Flexibility;
public double FlexibilityValue;*/
double flexibility=0;
double MaxFlexibility=0;


```
double MaxFS=0;
double MaxSD=0;
ActorSelectionValues.clear();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Retailer>0 && actor.get(i).Died<1)
{
//do calc for Flexibility
/*if (actor.get(i).MySuppliers.size()>0)
{
flexibility=1/actor.get(i).MySuppliers.size();
}
double FS=actor.get(i).Cash+actor.get(i).Profit;*/
MyValues thisMyValues= new MyValues
(actor.get(i),actor.get(i).SigmaDemand,0,0,0,0,0);
ActorSelectionValues.add(thisMyValues);
}
}
Collections.sort(ActorSelectionValues, new
SortActorSelectionValuesBySD ());
if (ActorSelectionValues.size()>0)
{
MaxSD=ActorSelectionValues.get(0).SDDemand;
traceln();
for (int i=0;i<ActorSelectionValues.size();i++)
{
ActorSelectionValues.get(i).SDDemandValue=ActorSelectionValue
s.get(i).SDDemand/MaxSD;
ActorSelectionValues.get(i).ThisActor.BuyingLocationValue=ActorS
electionValues.get(i).SDDemandValue;
}
}
traceln();
ActorSelectionValues.clear();
for (int i=0;i<actor.size();i++)
```

```
{
if (actor.get(i).Wholesaler>0 && actor.get(i).Died<1)
{
//do calc for Flexibility
/*if (actor.get(i).MySuppliers.size()>0)
{
flexibility=1/actor.get(i).MySuppliers.size();
}
double FS=actor.get(i).Cash+actor.get(i).Profit;*/
MyValues thisMyValues= new MyValues
(actor.get(i),actor.get(i).SigmaDemand,0,0,0,0,0);
ActorSelectionValues.add(thisMyValues);
}
}
Collections.sort(ActorSelectionValues, new
SortActorSelectionValuesBySD ());
if (ActorSelectionValues.size()>0)
{
MaxSD=ActorSelectionValues.get(0).SDDemand;
traceln();
for (int i=0;i<ActorSelectionValues.size();i++)
{
ActorSelectionValues.get(i).SDDemandValue=ActorSelectionValue
s.get(i).SDDemand/MaxSD;
ActorSelectionValues.get(i).ThisActor.BuyingLocationValue=ActorS
electionValues.get(i).SDDemandValue;
}
}
//sort ActorSelectionValues according to FS
//find largest and normalise ==> FS
```



```
//alocate values to variables at actor level
```

Function: CalculateFlexibilityValue

Description: Calculates Flexibility requirement of the buying agent based on their perception of global risk

Requires a calculation of global risk for each type of agent

General

Show At Runtime false

Return Type void

Code

Body //each agents flexibility requirement value is determined by its
perception of supply global risk
//ie retailers perceive the risk as being an ideal configuration of links
to wholesalers and
//manufacturers comapred to the actual links

Function: CalculateActualRisk

General

Show At Runtime false

Return Type void

Code

Body // simply collect actual demand for each agent and calulate variation

```
//actual risk = (COV(actual)+(unstaisfied demand/Total Demand))/2
CovDataSet.reset();
//establish satisfied demand COV
for (int i=0; i<actor.size();i++ )
{
if (actor.get(i).Died<1 && (actor.get(i).Wholesaler>0 ||
```

```
actor.get(i).Manufacturer>0) )
{
CovDataSet.add(actor.get(i).CurrentDemand);
}
}
if (CovDataSet.count()>0)
{
COVActualRetailerSuppliers=CovDataSet.deviation()/CovDataSet.
mean();
if (Double.isNaN(COVActualRetailerSuppliers))
{
COVActualRetailerSuppliers=0.1;
}
}
//establish optimal COV for this level of demand !!!!!!!!!!!!!!!!!!!!!!!!!!
//calculate COV risk
//calculate unsatisfied demand
//calculate total demand
//GlobalRetailBuyingRisk=(COVActualRetailerSuppliersCOVidealRetailerSuppliers)/(
MaxTheoreticalCOVCOVidealRetailerSuppliers);
```

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Calculating_commitment_16a6

Function: CalculateCurrentDemandManufacturers

General

Show At Runtime false

Return Type void

Code

```
Body CurrentManufacturingDemand=0;
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Manufacturer>0)
{
CurrentManufacturingDemand+=actor.get(i).CurrentDemand;
}
}
```

Function: SetOperationalCosts

General

Show At Runtime false

Return Type void

Code

```
Body //if called by an agent
if (agent.Retailer>0)
{
if (agent.CurrentDemand>0)
{
agent.OperatingCosts=agent.CurrentDemand*agent.Price*.8;
agent.BaseOPerationalDemand=agent.CurrentDemand;
agent.Cash=14*agent.OperatingCosts;
if (Double.isNaN(agent.Cash))
{
traceln();
}
}
else
{
agent.OperatingCosts=MinInitialCapacity*agent.Price*.8;
agent.BaseOPerationalDemand=MinInitialCapacity;
```

```
agent.Cash=14*agent.OperatingCosts;
if (Double.isNaN(agent.Cash))
{
traceln();
}
}
}
if (agent.Wholesaler>0)
{
if (agent.CurrentDemand>0)
{
agent.OperatingCosts=agent.CurrentDemand*agent.Price*.8;
agent.BaseOPerationalDemand=agent.CurrentDemand;
agent.Cash=30*agent.OperatingCosts;
if (Double.isNaN(agent.Cash))
{
traceln();
}
}
else
{
agent.OperatingCosts=MinInitialCapacity*agent.Price*.8;
```



```
agent.BaseOPerationalDemand=MinInitialCapacity;
agent.Cash=30*agent.OperatingCosts;
if (Double.isNaN(agent.Cash))
{
traceln();
}
}
}
if (agent.Manufacturer>0)
{
if (agent.CurrentDemand>0)
{
agent.OperatingCosts=agent.CurrentDemand*agent.Price*.8; //was
.4
agent.BaseOPerationalDemand=agent.CurrentDemand;
agent.Cash=60*agent.OperatingCosts;
if (Double.isNaN(agent.Cash))
{
traceln();
}
}
else
{
agent.OperatingCosts=MinInitialCapacity*agent.Price*.8;
agent.BaseOPerationalDemand=MinInitialCapacity;
agent.Cash=60*agent.OperatingCosts;
if (Double.isNaN(agent.Cash))
{
traceln();
}
}
}
//if called from main agent given by integer
```

Arguments:

Name	Type
agent	Actor

Function: CalculateMinInitialCapacity

General

Show At Runtime false

Return Type void

Code

```
Body MinCapacityData.reset();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Retailer<1 && actor.get(i).CurrentDemand>0)
{
MinCapacityData.add(actor.get(i).CurrentDemand);
}
}
MinInitialCapacity=MinCapacityData.min();
```

Function: CalculateMinimumRetailerDemand

General

Show At Runtime false

Return Type double

Code


```
Body double MinDemand;
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Retailer>0 && actor.get(i).Died<1)
{
RetailerDemand.add(actor.get(i).CurrentDemand);
}
}
MinDemand=RetailerDemand.min();
return MinDemand;
```

Function: MaxGlobalRiskCalculatation

General

Show At Runtime false

Return Type void

Code

```
Body
//sets CurrentIdealDemand=0
for (int i=0;i<actor.size();i++)
{
actor.get(i).CurrentIdealDemand=0;
}
SortRetailersByDemand();
SortRetailSuppliersByDemandMax();
//WholesaleSuppliersSortedByDemand.clear();
/*for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Manufacturer>0)
{
actor.get(i).CurrentIdealDemand=0;
}
}*/
//for each retailer
if (RetailSuppliersSortedByDemand.size()>0 &&
RetailersSortedByDemand.size()>0)
```

```
{
for (int i=0;i<RetailersSortedByDemand.size();i++)
{
RetailSuppliersSortedByDemand.get(0).SupplyDemand+=Retailers
SortedByDemand.get(i).BuyingDemand/2;
Collections.sort(RetailSuppliersSortedByDemand,new
SortRetailSuppliersByDemandMax());
RetailSuppliersSortedByDemand.get(0).SupplyDemand+=Retailers
SortedByDemand.get(i).BuyingDemand/2;
Collections.sort(RetailSuppliersSortedByDemand,new
SortRetailSuppliersByDemandMax());
}
traceln();
for (int i=0;i<RetailSuppliersSortedByDemand.size();i++)
```



```
{
RetailSuppliersSortedByDemand.get(i).Actor.CurrentIdealDemand=
RetailSuppliersSortedByDemand.get(i).SupplyDemand;
}
}
//now do the same for wholesalers to manufacturers
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Wholesaler>0 && actor.get(i).Died<1)
{
ActorDemand thisActorDemand=new
ActorDemand(actor.get(i),actor.get(i).CurrentIdealDemand,0 );
WholesalersSortedByDemand.add(thisActorDemand);
}
}
traceln();
Collections.sort(WholesalersSortedByDemand,new
SortWholesalersByDemand());
traceln();
//add wholesale suppliers to collection
WholesaleSuppliersSortedByDemand.clear();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Manufacturer>0 && actor.get(i).Died<1)
{
ActorDemand thisActorDemand=new
ActorDemand(actor.get(i),0,actor.get(i).CurrentIdealDemand );
WholesaleSuppliersSortedByDemand.add(thisActorDemand);
}
}
traceln();
Collections.sort(WholesaleSuppliersSortedByDemandMax,new
SortWholesalersByDemand());
traceln();
if (WholesaleSuppliersSortedByDemand.size()>0 &&
WholesalersSortedByDemand.size()>0)
{
for (int i=0;i<WholesalersSortedByDemand.size();i++)
{
WholesaleSuppliersSortedByDemand.get(0).SupplyDemand+=Who
lesalersSortedByDemand.get(i).BuyingDemand/2;
Collections.sort(WholesaleSuppliersSortedByDemand,new
SortWholesaleSuppliersByDemandMax());
WholesaleSuppliersSortedByDemand.get(0).SupplyDemand+=Who
lesalersSortedByDemand.get(i).BuyingDemand/2;
```

```
Collections.sort(WholesaleSuppliersSortedByDemand,new
SortWholesaleSuppliersByDemandMax());
}
traceln();
for (int i=0;i<WholesaleSuppliersSortedByDemand.size();i++)
{
WholesaleSuppliersSortedByDemand.get(i).Actor.CurrentIdealDem
and+=WholesaleSuppliersSortedByDemand.get(i).SupplyDemand;
}
}
traceln();
if (time()==2)
{
traceln();
```


```
}
WholesalersSortedByDemand.clear();
// todo: calculate COV ==> where to put this ==> not entire network
but partitioned according type !!!!!!!!!!!!!!!!!!!!!!!!!
CovDataSet.reset();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && (actor.get(i).Wholesaler>0 ||
actor.get(i).Manufacturer>0))
{
CovDataSet.add(actor.get(i).CurrentIdealDemand);
}
}
if (CovDataSet.count()>0)
{
COVMaxRetailerSuppliers=CovDataSet.deviation()/CovDataSet.me
an();
if (Double.isNaN(COVMaxRetailerSuppliers))
{
COVMaxRetailerSuppliers=0.1;
}
}
// calculate max imum value
/*double sum=0;
//double MaxCOV=0
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).Retailer>0 )
{
sum+=actor.get(i).CurrentDemand;
}
}
//count no of suppliers
double count=0;
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && (actor.get(i).Wholesaler >0 ||
actor.get(i).Manufacturer >0 ))
{
count+=1;
}
}
//allocate supply
double flag=0;
double MinRetailerDemand=CalculateMinimumRetailerDemand();
```

```
if (count>2) //!!!!!!!!!!!! WHAT HAPPENS IF JUST 1 SUPPLIER
!!!!!!!!!!!!!!!!! OR 2 SUPPLIERS
{
flag=1;
}
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && (actor.get(i).Wholesaler >0 ||
actor.get(i).Manufacturer >0 ))
{
if (flag==1)
{
//add sum-count-1
MaxCov.add (sum-(MinRetailerDemand/2)); // INSTEAD OF 1 THIS
SHOULD PROBABLY BE THE MNIMUM RETAILER CUSTOMER
DEMAND
MaxCov.add (MinRetailerDemand/2);
}
else
{
MaxCov.add(sum);
}
}
```



```
}*/
//MaxCov.add(1);
//MaxCov.add(sum-1);
//MaxTheoreticalCOV=MaxCov.deviation()/MaxCov.mean();
//MaxCov.reset();
//return MaxTheoreticalCOV ;//NEEDS TO BE CORRECTED FOR
THE RANGE
```

Function: SortRetailSuppliersByDemandMax

General

Show At Runtime false

Return Type void

Code

```
Body RetailSuppliersSortedByDemand.clear();
if (time()==1)
{
traceln();
}
for (int i=0;i<actor.size();i++)
{
if ((actor.get(i).Wholesaler>0 || actor.get(i).Manufacturer>0) &&
actor.get(i).Died<1)
{
//todo: calculate demand - by checking whether or not this actor has
been selected, and summing the current demnd
//sort retail suppliers by allocated demand (supply demand)
ActorDemand thisActorDemand=new ActorDemand(actor.get(i),0,
actor.get(i).CurrentIdealDemand);
RetailSuppliersSortedByDemand.add(thisActorDemand);
}
}
//todo: sort collection RetailersSortedByDemand
Collections.sort(RetailSuppliersSortedByDemand,new
SortRetailSuppliersByDemandMax());
traceln();
```

Function: SetHoldingCosts

General

Show At Runtime false

Return Type void

Code

Body

```
//have to start by calculating avg purchase price
if (thisActor.Retailer>0 || thisActor.Wholesaler>0)
{
for (int i=0;i<thisActor.MySuppliers.size();i++)
{
AvgPurchasePrice.add(thisActor.MySuppliers.get(i).Price);
}
}
if (thisActor.Manufacturer>0)
{
AvgPurchasePrice.add(ManufacturerPrice); // check this is linked to
intialisation
```



```
}
thisActor.AvgPurchasePrice=AvgPurchasePrice.mean();
if (thisActor.CurrentDemand>0)
{
thisActor.HoldingCosts=thisActor.HoldingRate*thisActor.CurrentDe
mand*thisActor.AvgPurchasePrice;
traceln();
thisActor.EconomicOrderQuantity=sqrt ( (2*
thisActor.CurrentDemand * 365 *thisActor.OrderCosts) /
(thisActor.HoldingCosts) );
traceln();
}
if (thisActor.CurrentDemand==0)
{
thisActor.HoldingCosts=thisActor.HoldingRate*thisActor.BaseOPer
ationalDemand*thisActor.AvgPurchasePrice;
traceln();
thisActor.EconomicOrderQuantity=sqrt ( (2*
thisActor.BaseOPerationalDemand * 365 *thisActor.OrderCosts) /
(thisActor.HoldingCosts) );
traceln();
}
AvgPurchasePrice.reset();
traceln();
// need to use base op demand if cd =0
```

Arguments:

Name Type

thisActor Actor

Function: CalculateDeliveryIndex

General

Show At Runtime false

Return Type void

Code

Body DeliveryStuffCollectionRetailer.clear();

```
DeliveryStuffCollectionWholesaler.clear();
DeliveryStuffCollectionManufacturer.clear();
double MaxSDRetailer=0;
```

```
double MaxSDWholesaler=0;
double MaxSDManufacturer=0;
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).Retailer>0)
{
DeliveryStuff thisDeliveryStuff = new
DeliveryStuff(actor.get(i),actor.get(i).SigmaDemand);
DeliveryStuffCollectionRetailer.add(thisDeliveryStuff);
}
}
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).Wholesaler>0)
{
DeliveryStuff thisDeliveryStuff = new
DeliveryStuff(actor.get(i),actor.get(i).SigmaDemand);
DeliveryStuffCollectionWholesaler.add(thisDeliveryStuff);
}
```



```
}
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).Manufacturer>0)
{
DeliveryStuff thisDeliveryStuff = new
DeliveryStuff(actor.get(i),actor.get(i).SigmaDemand);
DeliveryStuffCollectionManufacturer.add(thisDeliveryStuff);
}
}
//SortRetailersDS
Collections.sort(DeliveryStuffCollectionRetailer,new
SortRetailersDS());
Collections.sort(DeliveryStuffCollectionWholesaler,new
SortRetailersDS());
Collections.sort(DeliveryStuffCollectionManufacturer,new
SortRetailersDS());
traceln();
if (DeliveryStuffCollectionRetailer.size()>0)
{
MaxSDRetailer=DeliveryStuffCollectionRetailer.get(0).SigmaDema
nd;
}
if (DeliveryStuffCollectionWholesaler.size()>0)
{
MaxSDWholesaler=DeliveryStuffCollectionWholesaler.get(0).Sigma
Demand;
}
if(DeliveryStuffCollectionManufacturer.size()>0)
{
MaxSDManufacturer=DeliveryStuffCollectionManufacturer.get(0).Si
gmaDemand;
}
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).Retailer>0 &&
MaxSDRetailer>0)
{
actor.get(i).BuyingLocationValue=actor.get(i).SigmaDemand/MaxS
DRetailer;
```

```
}
if (actor.get(i).Died<1 && actor.get(i).Retailer>0 &&
MaxSDRetailer==0)
{
actor.get(i).BuyingLocationValue=0;
}
}
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).Wholesaler>0 &&
MaxSDWholesaler>0)
{
actor.get(i).BuyingLocationValue=actor.get(i).SigmaDemand/MaxS
DWholesaler;
}
if (actor.get(i).Died<1 && actor.get(i).Wholesaler>0 &&
MaxSDWholesaler==0)
{
actor.get(i).BuyingLocationValue=0;
}
}
```



```
{
actor.get(i).BuyingLocationValue=actor.get(i).SigmaDemand/MaxS
DManufacturer;
}
if (actor.get(i).Died<1 && actor.get(i).Manufacturer>0 &&
MaxSDManufacturer==0)
{
actor.get(i).BuyingLocationValue=0;
}
}
```

Function: CalculateMarginIndex

General

Show At Runtime false

Return Type void

Code

```
Body //DailyProfitCollection1.clear();
if (DailyProfitCollection1.size()>0)
{
traceln();
}
//sort DailyProfitCollection into types
// CHECK THAT ONLY ADDED IF ALIVE
if (DailyProfitCollection1.size()>0 && time()>30)
{
for (int i=0;i<DailyProfitCollection1.size();i++)
{
if (DailyProfitCollection1.get(i).thisActor.Retailer>0)
{
DailyProfitRetailer.add(DailyProfitCollection1.get(i));
}
}
//SORT
Collections.sort(DailyProfitRetailer,new SortActorsByMargin());
if (DailyProfitRetailer.size()>0)
{
MaxRetailerMarginVar=DailyProfitRetailer.get(0).Margin;
```

```
}
for (int i=0;i<DailyProfitCollection1.size();i++)
{
if (DailyProfitCollection1.get(i).thisActor.Retailer>0 &&
DailyProfitCollection1.get(i).thisActor.Died<1 )
{
DailyProfitCollection1.get(i).thisActor.BuyingPriceValue=1-
DailyProfitCollection1.get(i).Margin/MaxRetailerMarginVar;
}
}
traceln();
//for each in collection allocate margin value
for (int i=0;i<DailyProfitCollection1.size();i++)
{
if (DailyProfitCollection1.get(i).thisActor.Wholesaler>0)
{
DailyProfitWholesaler.add(DailyProfitCollection1.get(i));
}
}
//SORT
Collections.sort(DailyProfitWholesaler,new SortActorsByMargin());
if (DailyProfitWholesaler.size()>0)
{
```



```
MaxWholessalerMarginVar=DailyProfitWholesaler.get(0).Margin;
}
for (int i=0;i<DailyProfitCollection1.size();i++)
{
if (DailyProfitCollection1.get(i).thisActor.Wholesaler>0 &&
DailyProfitCollection1.get(i).thisActor.Died<1)
{
DailyProfitCollection1.get(i).thisActor.BuyingPriceValue=1-
DailyProfitCollection1.get(i).Margin/MaxWholessalerMarginVar;
}
}
for (int i=0;i<DailyProfitCollection1.size();i++)
{
if (DailyProfitCollection1.get(i).thisActor.Manufacturer>0)
{
DailyProfitManufacturer.add(DailyProfitCollection1.get(i));
}
}
//SORT
Collections.sort(DailyProfitManufacturer,new
SortActorsByMargin());
if (DailyProfitManufacturer.size()>0)
{
MaxManufacturerMarginVar=DailyProfitManufacturer.get(0).Margin;
}
for (int i=0;i<DailyProfitCollection1.size();i++)
{
if (DailyProfitCollection1.get(i).thisActor.Manufacturer>0 &&
DailyProfitCollection1.get(i).thisActor.Died<1)
{
DailyProfitCollection1.get(i).thisActor.BuyingPriceValue=1-
DailyProfitCollection1.get(i).Margin/MaxManufacturerMarginVar;
}
}
}
else
```

```
{
CalcMarginIndexNoValues();
}
Test();
for (int i=0;i<actor.size();i++)
{
actor.get(i).DailyCosts.reset();
actor.get(i).DailyRevenue.reset();
}
//DailyProfitCollection1.clear();
traceln();
//todo: clear DailyProfitCollection and daily profit stats collections
```

Function: CalculateDailyCosts

General

Show At Runtime false

Return Type void

Code

```
Body DailyProfitCollection1.clear();
for (int i=0;i<actor.size();i++)
```



```
{
actor.get(i).RollingDailyProfit.reset();
actor.get(i).DailyCosts.add
((actor.get(i).Stock*actor.get(i).AvgPurchasePrice*actor.get(i).Holdi
ngRate/365)+actor.get(i).OperatingCosts);
actor.get(i).Cash-=actor.get(i).DailyCosts.sum();
if (Double.isNaN(actor.get(i).Cash))
{
traceln();
}
actor.get(i).Cash+=actor.get(i).DailyRevenue.sum();
if (Double.isNaN(actor.get(i).Cash))
{
traceln();
}
actor.get(i).Profit=actor.get(i).DailyRevenue.sum()-
actor.get(i).DailyCosts.sum();
actor.get(i).DailyProfit.add(actor.get(i).Profit);
actor.get(i).DailyProfitVar=actor.get(i).Profit;
actor.get(i).DailyCostVar=actor.get(i).DailyCosts.sum();
actor.get(i).DailyRevenueVar=actor.get(i).DailyRevenue.sum();
if (actor.get(i).DailyProfit.size()>30)
{
for (int j= (actor.get(i).DailyProfit.size()-
30);j<actor.get(i).DailyProfit.size();j++)
{
actor.get(i).RollingDailyProfit.add(actor.get(i).DailyProfit.get(j));
}
MarginStuff thisStuff =new
MarginStuff(actor.get(i),actor.get(i).RollingDailyProfit.mean());
DailyProfitCollection1.add(thisStuff);
}
else
{
MarginStuff thisStuff =new
MarginStuff(actor.get(i),actor.get(i).Profit);
DailyProfitCollection1.add(thisStuff);
}
```

```
}
if (DailyProfitCollection1.size()>0)
{
traceln();
}
```

Function: CalcMarginIndexNoValues

General

Show At Runtime false

Return Type void

Code

```
Body RetailerMargin.reset();
WholesalerMargin.reset();
ManufacturerMargin.reset();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1)
{
if (actor.get(i).Retailer>0)
{
RetailerMargin.add(actor.get(i).BuyingPriceValue);
}
if (actor.get(i).Wholesaler>0)
{
```



```
WholesalerMargin.add(actor.get(i).BuyingPriceValue);
}
if (actor.get(i).Manufacturer>0)
{
ManufacturerMargin.add(actor.get(i).BuyingPriceValue);
}
}
}
MaxRetailerMarginVar=RetailerMargin.max();
MaxWholessalerMarginVar=WholesalerMargin.max();
MaxManufacturerMarginVar=ManufacturerMargin.max();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1)
{
if (actor.get(i).Retailer>0)
{
actor.get(i).BuyingPriceValue=1-
actor.get(i).BuyingPriceValue/MaxRetailerMarginVar;
}
if (actor.get(i).Wholesaler>0)
{
actor.get(i).BuyingPriceValue=1-
actor.get(i).BuyingPriceValue/MaxWholessalerMarginVar;
}
if (actor.get(i).Manufacturer>0)
{
actor.get(i).BuyingPriceValue=1-
actor.get(i).BuyingPriceValue/MaxManufacturerMarginVar;
}
}
}
```

Function: Test

General

Show At Runtime false

Return Type void

Code

```
Body traceln();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).BuyingPriceValue==0)
{
traceln();
}
}
```

Function: SetPricingFramework

General

Show At Runtime false

Return Type void

Code

```
Body
/*AvgManufacturerPrice=(1+ManufacturingMarginInput)*RawMateri
alPrice;
AvgWholesalePrice=(1+WholesalerMaginInput)*AvgManufacturerPr
ice;
AvgRetailPrice=(1+RetailerMarginInput)*AvgWholesalePrice;
```



```
RetailMaxPrice=AvgRetailPrice*(1+RetailPriceVariation);
WholesaleMaxPrice=AvgWholesalePrice*(1+WholesalePriceVariati
on);
ManufacturerMaxPrice=AvgManufacturerPrice*(1+ManufacturerPric
eVariation);
RetailMinPrice=AvgRetailPrice*(1-RetailPriceVariation);
WholesaleMinPrice=AvgWholesalePrice*(1-
WholesalePriceVariation);
ManufacturerMinPrice=AvgManufacturerPrice*(1-
ManufacturerPriceVariation);
traceln();*/
```

Function: ReallocateStock

General

Show At Runtime false

Return Type void

Code

```
Body //count number of equivilent agents still alive
int count=0;
double AmountToBeAllocated=0;
if (DeadAgent.Retailer>0)
{
for (int i=0; i<actor.size();i++)
{
if (actor.get(i).Retailer>0 && actor.get(i).Died<1)
{
count+=1;
}
}
AmountToBeAllocated=DeadAgent.Stock/count;
for (int i=0; i<actor.size();i++)
{
```

```
if (actor.get(i).Retailer>0 && actor.get(i).Died<1)
{
actor.get(i).Stock+=AmountToBeAllocated;
if (Double.isNaN(actor.get(i).Stock))
{
traceln();
}
//Pay for stock ??
}
}
}
if (DeadAgent.Wholesaler>0)
{
for (int i=0; i<actor.size();i++)
{
if (actor.get(i).Wholesaler>0 && actor.get(i).Died<1)
{
count+=1;
}
}
AmountToBeAllocated=DeadAgent.Stock/count;
for (int i=0; i<actor.size();i++)
{
if (actor.get(i).Wholesaler>0 && actor.get(i).Died<1)
{
```



```
actor.get(i).Stock+=AmountToBeAllocated;
//Pay for stock ??
if (Double.isNaN(actor.get(i).Stock))
{
traceln();
}
}
}
}
if (DeadAgent.Manufacturer>0)
{
for (int i=0; i<actor.size();i++)
{
if (actor.get(i).Manufacturer>0 && actor.get(i).Died<1)
{
count+=1;
}
}
AmountToBeAllocated=DeadAgent.Stock/count;
for (int i=0; i<actor.size();i++)
{
if (actor.get(i).Manufacturer>0 && actor.get(i).Died<1)
{
actor.get(i).Stock+=AmountToBeAllocated;
//Pay for stock ??
}
}
}
//reallocate stock
```

Arguments:

Name	Type
DeadAgent	Actor

Function: CalculateBaseOperationalDemand

General

Return Type void

Code

```
Body RetailBaseOpDemand.reset();
ManufacturerBaseOpDemand.reset();
WholesaleBaseOpDemand.reset();
//double SumOfRetailBaseOpDemand=0;
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).Retailer>0)
{
RetailBaseOpDemand.add(actor.get(i).BaseOPerationalDemand);
}
}
SumOfRetailBaseOpDemand=RetailBaseOpDemand.sum();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).Manufacturer>0)
{
ManufacturerBaseOpDemand.add(actor.get(i).BaseOPerationalDe
mand);
}
```



```
}
SumOfManufacturerBaseOpDemand=ManufacturerBaseOpDeman
d.sum();
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1 && actor.get(i).Wholesaler>0)
{
WholesaleBaseOpDemand.add(actor.get(i).BaseOPerationalDema
nd);
}
}
SumOfWholesalerBaseOpDemand=WholesaleBaseOpDemand.su
```

Function: RedistributeBaseOpDemand

General

Return Type void

Code

```
Body CalculateBaseOperationalDemand();
double tempBOD=0;
if ( DeadAgentType==3)
{
traceln();
}
if (DeadAgentType==1)
{
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Retailer>0 && actor.get(i).Died<1 )
{
if (actor.get(i).BaseOPerationalDemand==0
||SumOfRetailBaseOpDemand==0 || AmountToBeRedistributed
==0)
{
```

```
traceln();
}
actor.get(i).BaseOPerationalDemand+=(actor.get(i).BaseOPeration
alDemand/SumOfRetailBaseOpDemand)*
AmountToBeRedistributed;
}
}
}
if (DeadAgentType==2)
{
//redistribute stock
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Wholesaler>0 && actor.get(i).Died<1)
{
if (actor.get(i).BaseOPerationalDemand==0
||SumOfWholesalerBaseOpDemand==0 ||
AmountToBeRedistributed==0 )
{
traceln();
}
if (Double.isNaN(actor.get(i).Stock))
{
traceln();
}
tempBOD=actor.get(i).BaseOPerationalDemand;
```



```
AmountToBeRedistributed;
actor.get(i).Stock+=(tempBOD/SumOfWholesalerBaseOpDemand)*
StockToBeRedistributed;
if (Double.isNaN(actor.get(i).Stock))
{
traceln();
}
}
}
}
if (DeadAgentType==3)
{
//redistribute capacity and stock
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Manufacturer>0 && actor.get(i).Died<1)
{
tempBOD=actor.get(i).BaseOPerationalDemand;
actor.get(i).BaseOPerationalDemand+=(tempBOD/SumOfManufact
urerBaseOpDemand)*
AmountToBeRedistributed;
actor.get(i).Stock+=(tempBOD/SumOfManufacturerBaseOpDeman
d)*StockToBeRedistributed;
}
```

Arguments:

Name	Type
AmountToBeRedistributed	double
DeadAgentType	int
StockToBeRedistributed	double

Function: CreateNewAgents

General

Show At Runtime false

Return Type void

Code

Body //check to see if Retailers should be introduced

```
if (time()>TimeLastRetailerIntroduced+100)
{
create_Createnewretailer(uniform_discr(1,15));
TimeLastRetailerIntroduced=time();
}
//check to see if Wholesaler should be introduced
if (time()>TimeLastWholesalerIntroduced+150)
{
create_Createnewwholesaler(uniform_discr(1,15));
TimeLastWholesalerIntroduced=time();
}
//check to see if Manufacturer should be introduced
if (time()>TimeLastManufacturerIntroduced+300)
{
create_Createnewmanufacturer(uniform_discr(1,15));
TimeLastManufacturerIntroduced=time();
```



```
}
```

Function: SetOPerationalCostsForNewBorns

General

Show At Runtime false

Return Type double

Code

Body //operational costs= normal distribution around the mean of the type

```
//calculate the mean operational costs
// pass they type in the call
//Retailer=1;wholesaler=2;manufacturer=3
//return operatingCostsinput;
double sum=0;
double count=0;
double operatingCostsinput=0;
int noOfWholesalers=0;
int noOfManufacturers=0;
for (int i=0; i<actor.size();i++)
{
if (actor.get(i).Wholesaler>0 && actor.get(i).Died<1)
{
noOfWholesalers+=1;
}
}
for (int i=0; i<actor.size();i++)
{
if (actor.get(i).Manufacturer>0 && actor.get(i).Died<1)
{
noOfManufacturers+=1;
}
}
if (ActorType==1)
{
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Retailer>0 && actor.get(i).Died<1)
{
```

```
count=count+1;
sum= sum+ actor.get(i).OperatingCosts;
}
}
//calculate mean retailer operating costs - do this before the actor is
added
operatingCostsinput=( sum/count);
//return (operatingCostsinput);
}
if (ActorType==2)
{
if (noOfWholesalers>0)
{
//calculate mean wholesaler operating costs - do this before the
actor is added
for (int i =0;i<actor.size();i++)
{
if (actor.get(i).Wholesaler>0 && actor.get(i).Died<1)
{
count=count+1;
sum= sum+ actor.get(i).OperatingCosts;
```



```
//actor.get(i).Stock=20*RetailMarketValue/noOfWholesalers;
}
}
operatingCostsinput=(double)( sum/count);
//return (operatingCostsinput);
}
}
if (ActorType==2)
{
if (noOfWholesalers<1)
{
//calculate mean wholesaler operating costs - do this before the
actor is added
for (int i =0;i<actor.size();i++)
{
if (actor.get(i).Wholesaler>0 )
{
count=count+1;
sum= sum+ actor.get(i).OperatingCosts;
//actor.get(i).Stock=20*RetailMarketValue/noOfWholesalers;
}
}
operatingCostsinput=(double)( sum/count);
//return (operatingCostsinput);
}
}
if (ActorType==3)
{
//calculate mean retailer operating costs - do this before the actor is
added
if (noOfManufacturers>0)
{
for (int i =0;i<actor.size();i++)
{
if (actor.get(i).Manufacturer>0 && actor.get(i).Died<1)
{
count=count+1;
sum= sum+ actor.get(i).OperatingCosts;
```

```
//actor.get(i).Stock=20*RetailMarketValue/this.noOfManufacturers;
}
}
operatingCostsinput=(double)( sum/count);
//return (operatingCostsinput);
}
}
if (ActorType==3)
{
//calculate mean retailer operating costs - do this before the actor is
added
if (noOfManufacturers<1)
{
for (int i =0;i<actor.size();i++)
{
if (actor.get(i).Manufacturer>0 )
{
count=count+1;
sum= sum+ actor.get(i).OperatingCosts;
//actor.get(i).Stock=20*RetailMarketValue/this.noOfManufacturers;
}
}
operatingCostsinput=(double)( sum/count);
//return (operatingCostsinput);
```



```
}
}
traceln();
return (operatingCostsinput);
```

Arguments:

Name Type

ActorType double

Function: CalculateRetailDemand

General

Show At Runtime false

Return Type void

Code

```
Body RetailDemandStats.reset();
for (int i=0; i<actor.size();i++)
{
if (actor.get(i).Retailer>0 && actor.get(i).Died<1)
{
RetailDemandStats.add(actor.get(i).CurrentDemand);
}
}
RetailDemand=RetailDemandStats.sum();
```

Function: CheckProductionAndConsumption

General

Show At Runtime false

Return Type void

Code

```
Body Production.reset();
Consumption.reset();
TotalRetailDemand.reset();
TotalWholesaleAvailableStock.reset();
TotalManufacturingAvailableStock.reset();
```

```
TotalAllocatedStock.reset();
for (int i=0; i<actor.size();i++)
{
if (actor.get(i).Died<1 && (actor.get(i).Manufacturer>0 ))//||
actor.get(i).Wholesaler>0))
{
Production.add (actor.get(i).CurrentDemand);
TotalAllocatedStock.add(actor.get(i).AllocatedStock);
if (actor.get(i).Manufacturer>0 )
{
TotalManufacturingAvailableStock.add(actor.get(i).AvailableStock);
}
if (actor.get(i).Wholesaler>0)
{
TotalWholesaleAvailableStock.add(actor.get(i).AvailableStock);
}
}
if (actor.get(i).Died<1 && (actor.get(i).Retailer>0) &&
actor.get(i).AvailableStock>=actor.get(i).CurrentDemand )// ||
actor.get(i).Wholesaler>0))
{
```



```
Consumption.add (actor.get(i).CurrentDemand);
TotalRetailDemand.add(actor.get(i).CurrentDemand);
}
if (actor.get(i).Died<1 && (actor.get(i).Retailer>0) &&
actor.get(i).AvailableStock<actor.get(i).CurrentDemand )// ||
actor.get(i).Wholesaler>0))
{
Consumption.add (actor.get(i).AvailableStock);
TotalRetailDemand.add(actor.get(i).CurrentDemand);
}
}
TotalConsumption=Consumption.sum();
TotalProduction=Production.sum();
TotalRetaildemandValue=TotalRetailDemand.sum();
TotalWholesaleAvailableStockValue=TotalWholesaleAvailableStoc
k.sum();
TotalManufacturingAvaialableStockValue=TotalManufacturingAvail
ableStock.sum();
TotalAllocatedStockValue=TotalAllocatedStock.sum();
DailyOrdersReceived=DailyOrderCollection.sum();
DailyNSAsReceived=DailyNSACollection.sum();
DailyOrderCollection.reset();
DailyNSACollection.reset();
```

Function: CountManufacturersAlive

General

Show At Runtime false

Return Type void

Code

```
Body int count=0;
for (int i =0; i<actor.size(); i++)
{
if (actor.get(i).Manufacturer>0 && actor.get(i).Died<1)
{
count+=1;
}
}
```

```
if (count<1)
{
create_Createnewmanufacturer(0);
}
```

Function: CollectOutputData

General

Return Type void

Code

Body // at each time step capture any changes in relationships & capture number of

//changes and magnitude of changes

// capture time and magnitude of changes

Function: SettingInitialConditions

General

Return Type void

Code

Body // take parameters and calulate average prices

```
double TotalAddedValue=0;
double RetailAddedValue=0;
double WholesaleAddedValue=0;
double ManufacturingAddedValue=0;
//calculate total added value
TotalAddedValue=AvgRetailPrice-RawMaterialPrice;
//RetailAddedValue=TotalAddedValue*RetailerMarginInput;
WholesaleAddedValue=TotalAddedValue*WholesalerMaginInput;
ManufacturingAddedValue=TotalAddedValue*ManufacturingMargin
Input;
//set Manufacturing retail price first
AvgManufacturerPrice=RawMaterialPrice+ManufacturingAddedVal
ue;
ManufacturerMaxPrice=AvgManufacturerPrice+(ManufacturerPrice
Variation*AvgManufacturerPrice);
ManufacturerMinPrice=AvgManufacturerPrice(
ManufacturerPriceVariation*AvgManufacturerPrice);
//set wholesale price
AvgWholesalePrice=AvgManufacturerPrice+WholesaleAddedValue
;
WholesaleMaxPrice=AvgWholesalePrice+(WholesalePriceVariation
*AvgWholesalePrice);
WholesaleMinPrice=AvgWholesalePrice(
WholesalePriceVariation*AvgWholesalePrice);
//set retail max annd min
RetailMaxPrice=AvgRetailPrice+(RetailPriceVariation*AvgRetailPric
e);
RetailMinPrice=AvgRetailPrice(
RetailPriceVariation*AvgRetailPrice);
//take parameters and calculate min and max prices for each tier
```

Event: event

General

Show At Runtime false

Trigger Type timeout

Mode occuresOnce

Occurence Time 1

Action for (int i=0;i<actor.size();i++)

{

if (actor.get(i).Retailer>0)

{

dataset.add(actor.get(i).TargetMarketShare,actor.get(i).Price);

}

}

Event: event1

General

Show At Runtime false

Trigger Type timeout

Mode cyclic

Recurrence 1

Occurence Time 0

Action CalculateRetailDemand();

CalculateCurrentDemandManufacturers();

CalculateGlobalRisk();

CalculateActualRisk();

if (COVActualRetailerSuppliers>COVMaxRetailerSuppliers)

{

COVMaxRetailerSuppliers=COVActualRetailerSuppliers;

}

GlobalRetailBuyingRisk=COVActualRetailerSuppliers/COVMaxRet

ailerSuppliers;

if (GlobalRetailBuyingRisk>1 ||

Double.isNaN(GlobalRetailBuyingRisk))

{

GlobalRetailBuyingRisk=1;

}

CalculateBuyingLocationValue();

CalculateDeliveryIndex();

CalculateDailyCosts();

CalculateMarginIndex();

MarketShareAllocation();

traceln();

//CreateNewAgents();

CheckProductionAndConsumption();

Variable: noOfWholesalers

General

Show At Runtime false

Type int

Initial Value 0

Variable: GlobalStdDev

General

Show At Runtime false

Type double

Initial Value 0.3

Variable: RetailMarketValue

General

Show At Runtime false

Type double

Initial Value 0

Variable: noOfRetailers

General

Show At Runtime false

Type int

Initial Value 0

Variable: noOfManufacturers

General

Show At Runtime false

Type int

Initial Value 0

Variable: TotalNoOfAgents

General

Show At Runtime false

Type int

Initial Value 0

Variable: COVidealRetailerSuppliers

General

Show At Runtime false

Type double

Initial Value 0

Variable: COVActualRetailerSuppliers

General

Show At Runtime false

Type double

Initial Value 0

Variable: GlobalRetailBuyingRisk

General

Show At Runtime false

Type double

Initial Value 0

Variable: ManufacturerPrice

General

Show At Runtime false

Type double

Initial Value 3

Variable: BadBoyRef

General

Show At Runtime false

Type int

Initial Value 0

Variable: CurrentManufacturingDemand

General

Show At Runtime false

Type double

Initial Value 0

Variable: MinInitialCapacity

General

Show At Runtime false

Type double

Initial Value 0

Variable: COVMaxRetailerSuppliers

General

Show At Runtime false

Type double

Initial Value 0

Variable: MaxRetailerMarginVar

General

Show At Runtime false

Type double

Initial Value 0

Variable: MaxWholessalerMarginVar

General

Show At Runtime false

Type double

Initial Value 0

Variable: MaxManufacturerMarginVar

General

Show At Runtime false

Type double

Initial Value 0

Variable: TestCount

General

Show At Runtime false

Type double

Initial Value 0

Variable: RetailMaxPrice

General

Show At Runtime false

Type double

Initial Value 0

Variable: ManufacturerMinPrice

General

Show At Runtime false

Type double

Initial Value 0

Variable: WholesaleMinPrice

General

Show At Runtime false

Type double

Initial Value 0

Variable: RetailMinPrice

General

Show At Runtime false

Type double

Initial Value 0

Variable: ManufacturerMaxPrice

General

Show At Runtime false

Type double

Initial Value 0

Variable: WholesaleMaxPrice

General

Show At Runtime false

Type double

Initial Value 0

Variable: AvgRetailPrice

General

Show At Runtime false

Type double

Initial Value 15

Variable: AvgManufacturerPrice

General

Show At Runtime false

Type double

Initial Value 4

Variable: AvgWholesalePrice

General

Show At Runtime false

Type double

Initial Value 8

Variable: RawMaterialPrice

General

Show At Runtime false

Type double

Initial Value 2

Variable: SumOfRetailBaseOpDemand

General

Type double

Initial Value 0

Variable: TimeLastManufacturerIntroduced

General

Show At Runtime false

Type double

Initial Value 0

Variable: TimeLastRetailerIntroduced

General

Show At Runtime false

Type double

Initial Value 0

Variable: TimeLastWholesalerIntroduced

General

Show At Runtime false

Type double

Initial Value 0

Variable: RetailDemand

General

Show At Runtime false

Type double

Initial Value 0

Variable: TotalConsumption

General

Show At Runtime false

Type double

Initial Value 0

Variable: TotalProduction

General

Show At Runtime false

Type double

Initial Value 0

Variable: SumOfManufacturerBaseOpDemand

General

Type double

Initial Value 0

Variable: SumOfWholesalerBaseOpDemand

General

Type double

Initial Value 0

Variable: DailyOrdersReceived

General

Show At Runtime false

Type double

Initial Value 0

Variable: DailyNSAsReceived

General

Show At Runtime false

Type double

Initial Value 0

Variable: TotalRetaildemandValue

General

Show At Runtime false

Type double

Initial Value 0

Variable: TotalWholesaleAvailableStockValue

General

Show At Runtime false

Type double

Initial Value 0

Variable: TotalManufacturingAvaialableStockValue

General

Show At Runtime false

Type double

Initial Value 0

Variable: TotalAllocatedStockValue

General

Show At Runtime false

Type double

Initial Value 0

Variable: Replication

General

Show At Runtime false

Type int

Variable: ExperimentVersion

General

Show At Runtime false

Type int

Variable: TotalNoOfConnections

General

Show At Runtime false

Type double

Initial Value 0

Variable: TotalMagnitudeOfConnections

General

Show At Runtime false

Type double

Initial Value 0

Collection: ActorsRanked

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class ActorPrice

Collection: RetailersSortedByDemand

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class ActorDemand

Collection: WholesalersSortedByDemand

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class ActorDemand

Collection: RetailSuppliersSortedByDemand

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class ActorDemand

Collection: WholesaleSuppliersSortedByDemand

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class ActorDemand

Collection: ActorSelectionValues

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class MyValues

Collection: WholesaleSuppliersSortedByDemandMax

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class ActorDemand

Collection: DeliveryStuffCollectionRetailer

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class DeliveryStuff

Collection: DeliveryStuffCollectionWholesaler

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class DeliveryStuff

Collection: DeliveryStuffCollectionManufacturer

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class DeliveryStuff

Collection: DailyProfitCollection1

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class MarginStuff

Collection: DailyProfitRetailer

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class MarginStuff

Collection: DailyProfitWholesaler

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class MarginStuff

Collection: DailyProfitManufacturer

General

Show At Runtime false

Collection Class java.util.ArrayList

Element Class MarginStuff

Collection: Changes

General

Collection Class java.util.ArrayList

Element Class MySupplierRelationships

Environment: environment

General

Show At Runtime false

Enable Steps true

Step Duration 1

Before Step double NoOfLiveManufacturers=0;

double NoOfLiveWholesalers=0;

double NoOfLiveRetailers=0;

TotalNoOfConnections=0;

TotalMagnitudeOfConnections=0;

for (int i=0;i<actor.size();i++)

{

if (actor.get(i).Died<1)

{

```
actor.get(i).OldMysuppliersDetails.clear();
actor.get(i).NewMysuppliersDetails.clear();
actor.get(i).OldMysuppliersDetails1.clear();
actor.get(i).NewMysuppliersDetails1.clear();
if (actor.get(i).MySuppliers.size()>0)
{
TotalNoOfConnections+=actor.get(i).MySuppliers.size();
for (int j =0;j<actor.get(i).MySuppliers.size();j++)
{
MySupplierRelationships thisRelationship= new
MySupplierRelationships
(actor.get(i).MySuppliers.get(j),actor.get(i),actor.get(i).CurrentDema
nd/actor.get(i).MySuppliers.size(),0);
TotalMagnitudeOfConnections+=actor.get(i).CurrentDemand/actor.
get(i).MySuppliers.size();
actor.get(i).OldMysuppliersDetails.add(thisRelationship.Supplier.get
Index());
actor.get(i).OldMysuppliersDetails1.add(thisRelationship.Supplier.g
etIndex());
}
}
actor.get(i).CollaboratingProcess();
actor.get(i).CreateSelectionIndexForSuppliers();
}
}
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1)
{
if (actor.get(i).MySuppliers.size()>0)
{
for (int j =0;j<actor.get(i).MySuppliers.size();j++)
{
MySupplierRelationships thisRelationship= new
MySupplierRelationships
(actor.get(i).MySuppliers.get(j),actor.get(i),actor.get(i).CurrentDema
nd/actor.get(i).MySuppliers.size(),0);
actor.get(i).NewMysuppliersDetails.add(thisRelationship.Supplier.g
```



```
// compare old with new
actor.get(i).NewMysuppliersDetails.removeAll(actor.get(i).OldMysu
ppliersDetails1);
actor.get(i).OldMysuppliersDetails.removeAll(actor.get(i).NewMysu
ppliersDetails1);
}
}
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1)
{
if (actor.get(i).Retailer>0)
{
NoOfLiveRetailers+=1;
}
if (actor.get(i).Wholesaler>0)
{
NoOfLiveWholesalers+=1;
}
if (actor.get(i).Manufacturer>0)
{
```

```
NoOfLiveManufacturers+=1;
}
}
}
/*for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1)
{
if (actor.get(i).NewMysuppliersDetails.size()>0 && time()>0 )
{
for (int j=0;j<actor.get(i).NewMysuppliersDetails.size();j++)
{
int buyerident=actor.get(i).getIndex();
int supplierident=actor.get(i).NewMysuppliersDetails.get(j);
double
Magnitude=actor.get(i).CurrentDemand/actor.get(i).MySuppliers.siz
e();
database.modify
("INSERT INTO Results VALUES ( " + time() + "," +
ManufacturerPriceVariation +", "+ ManufacturingMarginInput + ", "+
RetailPriceVariation +" , " + WholesalePriceVariation +"," +
WholesalerMaginInput + " , "+ buyerident +" ," +supplierident + "," +
Magnitude +") ");
}
}
}
}*/
for (int i=0;i<actor.size();i++)
{
if (actor.get(i).Died<1)
{
if (actor.get(i).NewMysuppliersDetails.size()>0 && time()>0 )
{
for (int j=0;j<actor.get(i).NewMysuppliersDetails.size();j++)
{
int buyerident=actor.get(i).getIndex();
int supplierident=actor.get(i).NewMysuppliersDetails.get(j);
double
Magnitude=actor.get(i).CurrentDemand/actor.get(i).MySuppliers.siz
e();
file.println(ExperimentVersion +" "+ Replication + " " + time () + " " +
ManufacturerPriceVariation + " " + ManufacturingMarginInput + " "
+ RetailPriceVariation + " " +
WholesalePriceVariation + " " + WholesalerMaginInput + " " +
buyerident + " " + supplierident + " "
+ Magnitude + " " + TotalNoOfConnections + " " +
TotalMagnitudeOfConnections +" " + NoOfLiveRetailers + " " +
NoOfLiveWholesalers + " " + NoOfLiveManufacturers + " ");
}
```

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Calculating_commitment_16a6

Advanced

Space Type CONTINUOUS

Dynamic: Width 500

Dynamic: Height 500

Layout Type USER_DEF

Network Type USER_DEF

Actor: actor

General

Type Actor

Java Package Name calculating_commitment

Replication 0

Embedded Object Collection Type ARRAY_LIST_BASED

Envelopes environment

Stack Chart: chart

General

Scale Type AUTO

Analysis Auto Update true

Recurrence 1

Advanced

x -370

y -30

Width 260

Height 230

Appearance

Show Legend true

Legend Place SOUTH

Bars Direction UP

Bars Relative Width 0.8

Chart Items:

Title Color Value

AvgRetailPrice darkOrange AvgRetailPrice

AvgWholesalePrice mediumSeaGreen AvgWholesalePrice

AvgManufacturerPr

ice

slateBlue AvgManufacturerPrice

Time Plot: plot1

General

Time Window 1000

Vertical Scale AUTO

Analysis Auto Update true

Recurrence 1

Dataset Samples To Keep 1000

Advanced

x -420

y 310

Width 400

Height 340

Appearance

Show Legend true

Legend Place SOUTH

Label Format MODEL_TIME_UNITS

Plot Items:

Title Type Dataset / Value Point Style Color Line Width Interpolation

GlobalRetailBuying

Risk

value GlobalRetailBuyingRisk NONE crimson true 2 LINEAR

Data Set: dataset

General

Show At Runtime false

Axis Data Freeze X Axis false

Dataset Samples To Keep 100

Analysis Auto Update false

Statistics: CovDataSet

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: MaxCov

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: MinCapacityData

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: RetailerDemand

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: AvgPurchasePrice

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: RetailerMargin

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: WholesalerMargin

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: ManufacturerMargin

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: WholesaleBaseOpDemand

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Calculating_commitment_16a6

General

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: ManufacturerBaseOpDemand

General

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: RetailBaseOpDemand

General

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: RetailDemandStats

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: Production

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: Consumption

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: DailyOrderCollection

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Calculating_commitment_16a6

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: DailyNSACollection

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: TotalRetailDemand

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: TotalWholesaleAvailableStock

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: TotalManufacturingAvailableStock

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: TotalAllocatedStock

General

Show At Runtime false

Discrete true

Analysis Auto Update true

Recurrence 1

Data Set: dataset1

General

Axis Data Freeze X Axis true

Dataset Samples To Keep 100

Analysis Auto Update false

Embedded Object Presentation: actor_Presentation

Text: text4

Advanced

x 30

y 282

General

Alignment LEFT

Font Name SansSerif

Font Size 14

Bold Font Style true

Text Risk Calculations

Advanced

x 30

y 282

Database: database

General

DB Type EXCEL_ACCESS

DB File Name C:/Users/mn076059/Documents/Backup Sept 2010/My docs/cranfield/Thesis/Results/ThesisResults.accdb

Connection On Startup true

Text File: file

General

Show At Runtime false

Text File Type FILE

Text File Name C:/Users/mn076059/Documents/Backup Sept 2010/My docs/cranfield/Thesis/Results/Results.txt

File Mode WRITE_APPEND

Active Object Class: Actor

Calculating_commitment_16a6

General

Agent true

Advanced

Additional Code //using a comparator

```
public class FSSortByFS1 implements
Comparator<SupplierSelectionStuff>{
public int compare (SupplierSelectionStuff Manufacturer1,
SupplierSelectionStuff Manufacturer2){
Double Manufacturer1Score=Manufacturer1.FSScore;
Double Manufacturer2Score=Manufacturer2.FSScore;
if (Manufacturer1Score>Manufacturer2Score){
return -1;
}else if (Manufacturer1Score<Manufacturer2Score){
return 1;
}else {
return 0;
}
}
}
//using a comparator
public class DistSortByDist implements
Comparator<SupplierSelectionStuff>{
public int compare (SupplierSelectionStuff Manufacturer1,
SupplierSelectionStuff Manufacturer2){
Double Manufacturer1Score=Manufacturer1.DistanceScore;
Double Manufacturer2Score=Manufacturer2.DistanceScore;
if (Manufacturer1Score>Manufacturer2Score){
return 1;
}else if (Manufacturer1Score<Manufacturer2Score){
return -1;
}else {
return 0;
}
}
}
//using a comparator
public class PriceSortByPrice implements
Comparator<SupplierSelectionStuff>{
```

```
public int compare (SupplierSelectionStuff Manufacturer1,
SupplierSelectionStuff Manufacturer2){
Double Manufacturer1Score=Manufacturer1.PriceScore;
Double Manufacturer2Score=Manufacturer2.PriceScore;
if (Manufacturer1Score>Manufacturer2Score){
return 1;
}else if (Manufacturer1Score<Manufacturer2Score){
return -1;
}else {
return 0;
}
}
}
//using a comparator
public class SortBYUtility implements
Comparator<SupplierSelectionStuff>{
public int compare (SupplierSelectionStuff Manufacturer1,
SupplierSelectionStuff Manufacturer2){
Double Manufacturer1Score=Manufacturer1.SupplierUtility;
Double Manufacturer2Score=Manufacturer2.SupplierUtility;
if (Manufacturer1Score>Manufacturer2Score){
```



```
return -1;
}else if (Manufacturer1Score<Manufacturer2Score){
return 1;
}else {
return 0;
}
}
}
//using a comparator
public class FlexibilitySortByFlexibility implements
Comparator<SupplierSelectionStuff>{
public int compare (SupplierSelectionStuff Manufacturer1,
SupplierSelectionStuff Manufacturer2){
Double Manufacturer1Score=Manufacturer1.FlexibilityScore;
Double Manufacturer2Score=Manufacturer2.FlexibilityScore;
if (Manufacturer1Score>Manufacturer2Score){
return -1;
}else if (Manufacturer1Score<Manufacturer2Score){
return 1;
}else {
return 0;
}
}
}
```

Auto-create Datasets true

Recurrence 1

Dataset Samples To Keep 100

Agent

Space Type CONTINUOUS

Environment Defines Init Location true

On Receive if (msg.getClass()==Order.class)

```
{
Order thisOrder = (Order)msg; //cast it to the correct type
if (thisOrder.Buyer.Retailer>0)
{
get_Main().DailyOrderCollection.add(thisOrder.Quantity);
}
if (AvailableStock>=thisOrder.Quantity) //&&
```

```
averageDemand<=BaseOPerationalDemand) //check to see if
enough stock
{//Calculate LT
traceln();
double distance=
(getDistance(this.getX(),this.getY(),get_Main().actor.get(thisOrder.B
uyer.getIndex()).getX(),get_Main().actor.get(thisOrder.Buyer.getInd
ex()).getY()))*10 ;
double LT=round( 1+( ( (distance/50) /24)+.5) );//1 day to
process order
//create Replenishment ==>event/class
AllocatedStock=AllocatedStock+thisOrder.Quantity;
AvailableStock=Stock-AllocatedStock;
DemandForOpCosts.add(thisOrder.Quantity);
//check to see if enough stock
create_Replenishment(LT,thisOrder.Quantity,thisOrder.Buyer,this);
thisOrder.Buyer.NoOfReplenishments=thisOrder.Buyer.NoOfReple
nishments+1;
OrdersReceived=OrdersReceived+thisOrder.Quantity;
if (!MyExistingCustomers.contains(thisOrder.Buyer))
{
MyExistingCustomers.add(thisOrder.Buyer);
}
Page 63 of 129
Calculating_commitment_16a6

if (!thisOrder.Buyer.MyCollaboratingSuppliers.contains(this))
{
OrderHistory1=OrderHistory1+thisOrder.Quantity;
if (Wholesaler>0 || Manufacturer>0)
{
MyProduction=MyProduction+thisOrder.Quantity;
}
}
}
else
{
//send NSA
traceln();
NSA thisNSA = new
NSA(thisOrder.Buyer,thisOrder.Quantity,this,get_Main().BadBoyRef
);
get_Main().BadBoyRef=get_Main().BadBoyRef+1;
send(thisNSA,thisOrder.Buyer);
NSASent=NSASent+ thisOrder.Quantity;
OrdersReceived=OrdersReceived+thisOrder.Quantity;
OrderHistory.add(thisOrder.Quantity);
OrderHistory1=OrderHistory1+thisOrder.Quantity;//++++++++++++
++++++++++++++++++++++++++++++++++
}
}
if (msg.getClass()==NSA.class)
{
NSA thisNSA = (NSA)msg; //cast it to the correct type
if (Retailer>0)
{
get_Main().DailyNSACollection.add(thisNSA.OrderQty);
}
ExpectedStock=ExpectedStock-thisNSA.OrderQty;
NSAreceived=NSAreceived+1;
//BadBoyClass thisBadBoyClass= new
BadBoyClass(thisNSA.Sendor,thisNSA.BadBoyRef);
```

```
//BadBoys.add(thisBadBoyClass);
NSAsReceived.add(thisNSA);
CheckIfTooManyNSAs(thisNSA);
//what to do about bad boys
//create event to remove bad boy after say 90 days
//create_CleanBadBoys(10,thisNSA.Sendor,thisNSA.BadBoyRef);
Statechart Refs []
Before Step /*if (Retailer>0)
{
DemandForOpCosts.add(CurrentDemand);
}
UpdateOperationalCosts();
NSASent=0;
CalculatingHoldingCosts();
StockCalcs();
MyProduction=0;
MyConsumption=0;*/
if (Manufacturer>0 && Status.isStateActive(Alive))
{
MySizeAndType.setFillColor(blue);
}
if (Wholesaler>0 && Status.isStateActive(Alive))
{
MySizeAndType.setFillColor(yellow);
}
if (Retailer>0 && Status.isStateActive(Alive))
{
```



```
MySizeAndType.setFillColor(red);
}
if (Died<1)
{
if (NSASent>1 && OrdersReceived>1)
{
Quality=1- (NSASent/OrdersReceived);
}
else
{
Quality=1;
}
MyGlobalRiskPerception();
CalculateQualityValue();
RetailerSalesCash();
ConsumeStock();
CalculateCommitment();
CalculateBuyerFlexibilityRequirement();
CalculateFSValue();
//Cash+=DailyRevenue.sum();
//Cash-=DailyVariableCosts.sum();
//DailyRevenue.reset();
//DailyVariableCosts.reset();
//CalculateDailyCosts();
//++++++++++++++++++++++++++++++++++++++++++++++++++
++++++
//Changes();
//++++++++++++++++++++++++++++++++++++++++++++++++++
+++++++++
if (time()==0)
{
CalcInitialStock();
```

```
}
CalculatingHoldingCosts();
StockCalcs();
Ordering();
CalculateDailyDemand();
//get_Main().CalculateGlobalRisk();
//get_Main().CalculateDemandForSuppliers();
//OrganiseSupplyBaseData(this,get_Main().actor.get(5));
//todo:
//Adaptation();
//============================================>>>>
>>>
if (Double.isNaN(Stock))
{
traceln();
}
}
DrawConnections();
On Step //CalculateDailyCosts();
```


Dynamic Event: ManufacturingRequest

General

```
Action Stock=Stock+Quantity;
ExpectedStock=ExpectedStock-Quantity;
MyConsumption=MyConsumption+Quantity;
DailyVariableCosts.add(Quantity*Price*.2);
VariableCosts.add(Quantity*Price*.2);
```

Parameters:

Name	Type
Quantity	double

Dynamic Event: Replenishment

General

Action

```
int i = Buyer.getIndex();
int j= Seller.getIndex();
if ((i==14 || j==14) && time()==356)
{
traceln();
```



```
}
/*get_Main().actor.get(i).Stock=get_Main().actor.get(i).Stock+Order
edQuantity;
get_Main().actor.get(i).Cash=
get_Main().actor.get(j).Price*OrderedQuantity;
get_Main().actor.get(j).Cash+=get_Main().actor.get(j).Price*Ordere
dQuantity;*/
get_Main().actor.get(i).ExpectedStock=get_Main().actor.get(i).Expe
ctedStock-OrderedQuantity;
get_Main().actor.get(i).MyConsumption=get_Main().actor.get(i).My
Consumption+OrderedQuantity;
get_Main().actor.get(i).Stock+=OrderedQuantity;
if (Double.isNaN(get_Main().actor.get(i).Stock))
{
traceln();
}
```

```
if ((i==14 || j==14) && time()==355)
{
traceln();
}
//get_Main().actor.get(j).Stock=get_Main().actor.get(j).StockOrderedQuantity;
Stock-=OrderedQuantity;
if (Double.isNaN(Stock))
{
traceln();
}
if ((Stock)<0)
{
int Phil=0;
}
/*get_Main().actor.get(j).AllocatedStock=
get_Main().actor.get(j).AllocatedStock-OrderedQuantity;
get_Main().actor.get(j).RevenueData.add((OrderedQuantity*get_Ma
in().actor.get(j).Price));
get_Main().actor.get(j).DailyRevenue.add((OrderedQuantity*get_M
ain().actor.get(j).Price));*/
AllocatedStock-=OrderedQuantity;
RevenueData.add((OrderedQuantity*Price));
DailyRevenue.add((OrderedQuantity*Price));
get_Main().actor.get(i).PurchaseCostPerUnit=Price;//get_Main().act
or.get(j).Price;
get_Main().actor.get(i).DistributionCostsPerUnit =
(getDistance(get_Main().actor.get(i).getX(),get_Main().actor.get(i).g
etY(),this.getX(),this.getY())*10)
*get_Main().actor.get(i).CostPerKm/OrderedQuantity;
//traceln ("actor i Purchase cost per nit" + " " +
get_Main().actor.get(i).PurchaseCostPerUnit);
//traceln ("actor i distributioncosts per unit" + " " +
get_Main().actor.get(i).DistributionCostsPerUnit);
//adjust cash for distribution
//get_Main().actor.get(i).Cash=
get_Main().actor.get(i).DistributionCostsPerUnit*OrderedQuantity;
if (DistributionCostsPerUnit>infinity)
{
int p=1;
}
double buyerLocX=get_Main().actor.get(i).getX();
double BuyerLocY=get_Main().actor.get(i).getY();
double SellerLocX=this.getX(); //get_Main().actor.get(j).getX();
double SellerLocy= this.getY();// get_Main().actor.get(j).getY();
get_Main().actor.get(i).VariableCosts.add(OrderedQuantity*(get_M
ain().actor.get(i).PurchaseCostPerUnit+get_Main().actor.get(i).Distri
butionCostsPerUnit));
traceln("daily variable costs for i" + " " +
OrderedQuantity*(get_Main().actor.get(i).PurchaseCostPerUnit+get
```


```
(i).DistributionCostsPerUnit));
get_Main().actor.get(i).DailyVariableCosts.add(OrderedQuantity*(g
et_Main().actor.get(i).PurchaseCostPerUnit+get_Main().actor.get(i).
DistributionCostsPerUnit));
traceln ("order quantity" + " " + OrderedQuantity);
traceln("sum of daily variable costs" + " " +
get_Main().actor.get(i).DailyVariableCosts.sum());
get_Main().actor.get(i).VariableCostPerUnit=get_Main().actor.get(i).
PurchaseCostPerUnit+get_Main().actor.get(i).DistributionCostsPer
Unit
```

```
+get_Main().actor.get(i).HoldingCostsPerUnit;
get_Main().actor.get(i).DistributionCostsPerUnit1=get_Main().actor.
get(i).DistributionCostsPerUnit;
get_Main().actor.get(i).BuyPrice=get_Main().actor.get(i).PurchaseC
ostPerUnit;
if (Manufacturer>0)//Seller.Manufacturer>0)
{
/*get_Main().actor.get(j).VariableCosts.add(OrderedQuantity*(.4*get
_Main().actor.get(j).Price ));
get_Main().actor.get(j).DailyVariableCosts.add(OrderedQuantity*(.4
*get_Main().actor.get(j).Price ));*/
VariableCosts.add(OrderedQuantity*(.4*Price ));
DailyVariableCosts.add(OrderedQuantity*(.4*Price ));
}
if ((i==14 || j==14) && time()==355 )
{
traceln();
}
```

Parameters:

Name Type

OrderedQuantity double

Buyer Actor

Seller Actor

Dynamic Event: CleanBadBoys

General

Action for (int i=0;i<BadBoys.size();i++)

```
{
if (BadBoys.get(i).BadBoy==ActorToClean &&
BadBoys.get(i).BadBoyRef==BadBoyRef)
{
BadBoys.remove(i);
}
}
```

Parameters:

Name Type

ActorToClean Actor

BadBoyRef int

Function: CreateSelectionIndexForSuppliers

Description: checked to see that arrays are poulated appropriately and that indexes are calculated correctly

concern that whether to use index or ranking, and whether inferior index is representative of poorer financial security

NEED TO CHECK BADBOYS ARE BEING HANDLED

General

Return Type void

Code

Body

```
double NormalisingScore=0;
double NormalisingDistance=0;
double NormalisingPrice=0;
double FSScore=0;
double NormalisingFlexibility=0;
double TotalValue=0;
double BuyingFSWeight=0;
double BuyingLocationWeight=0;
double BuyingPriceWeight=0 ;
double BuyingQualityWeight=0;
```

```
double BuyerCommitmentReqWeight=0;
double BuyerFlexibilityRequirement=0;
SupplierUtilityCollection.clear();
TotalValue=BuyingFSValue+BuyingLocationValue+BuyingPriceVal
ue+BuyerFlexibilityRequirement+BuyingQualityValue;
if (MySuppliers.isEmpty())
{
BuyerFlexibilityRequirement=0;
BuyingPriceWeight=0;
}
else
{
BuyerFlexibilityRequirement=(1/MySuppliers.size());
BuyerCommitmentReqWeight=
((1/(MySuppliers.size())/TotalValue));
}
BuyingFSWeight=BuyingFSValue/TotalValue;
BuyingLocationWeight= BuyingLocationValue/TotalValue;
BuyingPriceWeight= BuyingPriceValue/TotalValue;
BuyingQualityWeight=BuyingQualityValue/TotalValue;
traceln();
if (Wholesaler>0)
{
for (int i=0;i<get_Main().actor.size();i++)
{
if(get_Main().actor.get(i).Died<1 &&
get_Main().actor.get(i).Manufacturer>0)
{
double temp=get_Main().actor.get(i).Price;
traceln();
SupplierSelectionStuff thisStuff=
OrganiseSupplyBaseData(get_Main().actor.get(i),this);
traceln();
SupplierUtilityCollection.add(thisStuff);
}
}
NormaliseAndRank();
traceln();
}
traceln();
if (Retailer>0)
```



```
{
for (int i=0;i<get_Main().actor.size();i++)
{
if(get_Main().actor.get(i).Died<1 &&
(get_Main().actor.get(i).Manufacturer>0
|| get_Main().actor.get(i).Wholesaler>0))
{
//get supply base data, and organise for selection
SupplierSelectionStuff thisStuff=
OrganiseSupplyBaseData(get_Main().actor.get(i),this);
SupplierUtilityCollection.add(thisStuff);
}
}
//sort to establish normalising values
NormaliseAndRank();
traceln();
}
//Calculate Utility
```

```
for(int i =0; i<SupplierUtilityCollection.size();i++)
{
double utility=
SupplierUtilityCollection.get(i).FSRank*BuyingFSWeight
+
SupplierUtilityCollection.get(i).DistanceRank*BuyingLocationWeight
+
SupplierUtilityCollection.get(i).PriceRank*BuyingPriceWeight
+
SupplierUtilityCollection.get(i).QualityRank*BuyingQualityWeight;
SupplierUtilityCollection.get(i).SupplierUtility=utility;
for (int j=0; j<MyCollaboratingSuppliers.size(); j++)
if
(MyCollaboratingSuppliers.get(j)==SupplierUtilityCollection.get(i).Su
pplier)
{
if (SupplierUtilityCollection.get(i).SupplierUtility*1.05<.9)
{
SupplierUtilityCollection.get(i).SupplierUtility=SupplierUtilityCollectio
n.get(i).SupplierUtility*1.05;
}
}
}
Collections.sort(SupplierUtilityCollection,new SortBYUtility());
traceln();
//==================================================
===========
/*if ((this.Retailer>0 || this.Wholesaler>0) &&
(SupplierUtilityCollection.size()> (BadBoys.size())) )
{
if (BadBoys.size()>0)
{
for (int j=0;j<BadBoys.size();j++)
{
for (int i=0;i<SupplierUtilityCollection.size();i++)
{
if (BadBoys.get(j).BadBoy==SupplierUtilityCollection.get(i).Supplier)
{
SupplierUtilityCollection.remove(i);
}
}
}
```

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```
size()+1
if (SupplierUtilityCollection.size()>0)
{
MySuppliers.clear();
MySuppliers.add(SupplierUtilityCollection.get(0).Supplier);
if (MyGlobalRiskPerceptionValue>.5 &&
SupplierUtilityCollection.size()>1)
{
MySuppliers.add(SupplierUtilityCollection.get(1).Supplier);
}
CalculateCommitment();
CalculateRelationalRisk();
//!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
//!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
// remove badBoys
//!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
//!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
```

```
/*if (MySuppliers.size()>1 &&
(MyRelationshipCommitments.get(0).RelationshipRisk>.5 ||
MyGlobalRiskPerceptionValue>.5))
{
MySuppliers.add(SupplierUtilityCollection.get(1).Supplier);
}*/
//}
//Calculate risk
//=================================================
============
/*if (this.Retailer>0 || this.Wholesaler>0)
{
for (int i=0;i<2;i++) //todo: make this fit the purchasing strategy
{
MySuppliers.add(SupplierUtilityCollection.get(i).Supplier);
}
}*/
//DrawConnections();
}
```

Function: DrawConnections

General

Return Type void

Code

```
Body //line.setDx(WholesalerDistanceTable.get(0).myX - getX());
// clear all lines
Connection.setDx(0);
Connection.setDy(0);
Connection1.setDx(0);
Connection1.setDy(0);
if (Died<1)
{
if (MySuppliers.size()>0 && CurrentDemand>0 && Died<1)
{
Connection.setDx(MySuppliers.get(0).getX()-getX());
Connection.setDy(MySuppliers.get(0).getY()-getY());
//Connection.setLineWidth(1+CurrentDemand/1000);
Connection1.setDx(0);
Connection1.setDy(0);
if (MySuppliers.size()>1 && CurrentDemand>0)
{
Connection1.setDx(MySuppliers.get(1).getX()-getX());
```



```
Connection1.setDy(MySuppliers.get(1).getY()-getY());
//Connection1.setLineWidth(1+CurrentDemand/1000);
}
}
//Connection.SetDy(MySuppliers.get(0).getY()-getY());
}
```

Function: OrganiseSupplyBaseData

General

Return Type SupplierSelectionStuff

Code

```
Body traceln();
double TotalPrice=0;
double FlexibilityScore =0;
double FSScore=Supplier.Cash+Supplier.Profit;
```

```
double distance=
(getDistance(this.getX(),this.getY(),Supplier.getX(),Supplier.getY()))
*10 ;
double tempCurrentDemand=CurrentDemand;
double tempEconomicOrderQuantity=0;
double tempDistributionCosts=0;
if (time()==10)
{
traceln();
}
if (MySuppliers.size()>0)
{
double SupplierDependency =
(CurrentDemand/(double)MySuppliers.size())
/Supplier.CurrentDemand ;
double BuyerDependency = 1/(double)MySuppliers.size();
FlexibilityScore =(SupplierDependency+BuyerDependency)/2;
}
else
{
FlexibilityScore =0;
}
double QualityScore=Supplier.Quality;
//do price to include distribution
if (Buyer.Wholesaler>0)
{
traceln();
}
double tempSupplierPrice=Supplier.Price;
double
tempDistance=getDistance(Supplier.getX(),Supplier.getY(),Buyer.g
etX(),Buyer.getY())*10;
double tempCostPerKm=Supplier.CostPerKm;
if (CurrentDemand==0)
{
HoldingCosts=HoldingRate*BaseOPerationalDemand*AvgPurchas
ePrice;
tempEconomicOrderQuantity=sqrt(2*CurrentDemand*(OrderCosts/
HoldingCosts));
tempDistributionCosts=distance*CostPerKm/tempEconomicOrderQ
uantity;
}
if (CurrentDemand>0)
{
HoldingCosts=HoldingRate*CurrentDemand*AvgPurchasePrice;
```


```
}
TotalPrice=Supplier.Price + tempDistributionCosts;//+
((getDistance(Supplier.getX(),Supplier.getY(),Buyer.getX(),Buyer.g
etY())*10)
// *Supplier.CostPerKm/Buyer.EconomicOrderQuantity);
traceln();
SupplierSelectionStuff thisStuff=new SupplierSelectionStuff
(Supplier,FSScore,distance,TotalPrice,FlexibilityScore,QualityScore
,0,0,0,0,QualityScore,0);
```

Arguments:

Name Type
Supplier Actor
Buyer Actor

Function: NormaliseAndRank

General

Return Type void

Code

Body //sort to establish normalising values

```
Collections.sort(SupplierUtilityCollection,new FSSortByFS1());
if (SupplierUtilityCollection.size()>0)
{
double NormalisingScore=SupplierUtilityCollection.get(0).FSScore;
Collections.sort(SupplierUtilityCollection,new DistSortByDist());
double
NormalisingDistance=SupplierUtilityCollection.get(0).DistanceScore
;
Collections.sort(SupplierUtilityCollection,new PriceSortByPrice());
double
NormalisingPrice=SupplierUtilityCollection.get(0).PriceScore;
traceln();
Collections.sort(SupplierUtilityCollection,new
FlexibilitySortByFlexibility());
double
NormalisingFlexibility=SupplierUtilityCollection.get(0).FlexibilityScor
e;
//Rank suppliers
for(int i =0; i<SupplierUtilityCollection.size();i++)
{
SupplierUtilityCollection.get(i).FSRank=SupplierUtilityCollection.get
(i).FSScore/NormalisingScore;
SupplierUtilityCollection.get(i).DistanceRank=1/(SupplierUtilityColle
ction.get(i).DistanceScore/NormalisingDistance);
SupplierUtilityCollection.get(i).PriceRank=1/(SupplierUtilityCollectio
n.get(i).PriceScore/NormalisingPrice);
SupplierUtilityCollection.get(i).FlexibilityRank=SupplierUtilityCollecti
```

Function: CalculateCommitment

Description: Calculates the buyer and seller committments for any given relationship

General

Return Type void

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Code

Body //Commitment=cube root (GR*RR*EuDist)

```
//RR=BD+SD/2
//SupplierScore
MyRelationshipCommitments.clear();
double SupplierCommitment = 0;
double BuyerCommitment = 0;
//todo: make sure have suppliers or customers
if ( MySuppliers.size()>0 && Died<1)
{
BuyerCommitment = 1/(double)MySuppliers.size();
for (int i=0;i<MySuppliers.size();i++)
{
if (MySuppliers.get(i).Died<1)
{
SupplierCommitment=
(CurrentDemand/(double)MySuppliers.size())
/MySuppliers.get(i).CurrentDemand ;
RelationshipCommitment thisRelationship = new
```

```
RelationshipCommitment
(this,MySuppliers.get(i),"Buyer","Supplier",BuyerCommitment,Suppl
ierCommitment,0);
MyRelationshipCommitments.add(thisRelationship);
}
}
}
if ( MyCustomers.size()>0 && Died<1)
{
//sum all mycustomers demand taking into account no of suppliers
// find this customer's demand
for (int i=0;i<MyCustomers.size();i++)
{
if (MyCustomers.get(i).Died<1)
{
SupplierCommitment =
(MyCustomers.get(i).CurrentDemand/MyCustomers.get(i).MySuppli
ers.size())/CurrentDemand;
BuyerCommitment=
1/(double)MyCustomers.get(i).MySuppliers.size();
RelationshipCommitment thisRelationship = new
RelationshipCommitment
(this,MyCustomers.get(i),"Supplier","Buyer",BuyerCommitment,Sup
plierCommitment,0);
MyRelationshipCommitments.add(thisRelationship);
}
```

Function: CalculateRelationalRisk

Description: Calculates the relational risk for any relationship as the difference between buyer and seller commitment

General

Return Type void

Code

```
Body for (int i=0;i<MyRelationshipCommitments.size();i++)
{
double RelationalRisk= abs(
(MyRelationshipCommitments.get(i).MyCommitmentMyRelationshipCommitments.
get(i).PartnerCommitment) );
MyRelationshipCommitments.get(i).RelationshipRisk=RelationalRis
k;
```

Function: CalcInitialStock

General

Return Type void

Code

```
Body //CurrentDemand=0;
//find max demand
if (Wholesaler>0)
{
for (int i= 0; i <get_Main().actor.size();i++)
{
if (get_Main().actor.get(i).MySuppliers.contains(this))
{
CurrentDemand=CurrentDemand+(get_Main().actor.get(i).CurrentD
emand/get_Main().actor.get(i).MySuppliers.size());
Stock=CurrentDemand*20;
}
//else
//{
```

```
//Stock=10000;
//}
}
if (CurrentDemand==0)
{
Stock=10000;
}
}
if (Manufacturer>0)
{
for (int i= 0; i <get_Main().actor.size();i++)
{
if (get_Main().actor.get(i).MySuppliers.contains(this))
{
CurrentDemand=CurrentDemand+(get_Main().actor.get(i).CurrentD
emand/get_Main().actor.get(i).MySuppliers.size());
Stock=CurrentDemand*20;
}
//else
//{
//Stock=10000;
//}
}
if (CurrentDemand==0)
{
Stock=10000;
}
}
```

Function: StockCalcs

Description: Safety stock claculation

returns

- safety stock
- EOQ
- SigmaDemand (if no history)

CHECK THAT SIGMAD CALCULATED PROPERLY FOR RETAILERS WHEN VARIATION INTRODUCED THRO MKTSHARECALC

General

Return Type void

Code

Body

```
//double ManufacturingLeadTime=0;
//==================================================
```



```
==================================================
===========================================
//calculate lead time
//==================================================
==================================================
===========================================
if (this.Retailer>0 || this.Wholesaler>0 && MySuppliers.size()>0)
{
for (int i=0; i<MySuppliers.size();i++)
{
// check to see if suitable
double distance=
(getDistance(this.getX(),this.getY(),get_Main().actor.get(i).getX(),ge
t_Main().actor.get(i).getY()))*10 ;
double LT=round( 2+( ( (distance/50) /24)+.5) );
MyStatistics.add(LT);
```

```
}
// make assumption about SigmaDemand if 0 then set at 10% of
currentidealdemand
if (RollingDemandStats.count()<30)
{
SigmaDemand=.1*CurrentDemand; //check that current demand is
set on startup
}
if (RollingDemandStats.count()>30)
{
SigmaDemand=RollingDemandStats.deviation();
}
AverageLeadTime=MyStatistics.max();
SafetyStock=(1.65*SigmaDemand*sqrt(AverageLeadTime));
ROP=((AverageLeadTime+2)*CurrentDemand)+SafetyStock;
//==================================================
==================================================
==========================================
//cvalculate average Price
//==================================================
==================================================
=========================================
//use my suppliers to establish average purchase price
double PurchasePrice=0;
if (MySuppliers.size()>0)
{
for (int i=0;i<MySuppliers.size();i++)
{
PurchasePrice+=MySuppliers.get(i).Price;
}
AvgPurchasePrice=PurchasePrice/MySuppliers.size();
}
//==================================================
================================
// Calculate inventory management functions
//==================================================
==================================
HoldingCostsPerUnit=AvgPurchasePrice*HoldingRate;
EconomicOrderQuantity=(sqrt( (2* CurrentDemand*365
*OrderCosts)/(HoldingCosts) ));
if (RollingDemandStats.count()>0 &&
Retailer<1)///++++++++++++++++++++++++++++++++++++++++++
+++++++++++!!!!!!!!!!!
{
SigmaDemand=RollingDemandStats.deviation();
//Maybe catch event where RDS.Mean =0 and dont change CD in
this event
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}
//AverageLeadTime=MyStatistics.mean();
SafetyStock=(1.65*SigmaDemand*sqrt(AverageLeadTime));
HoldingCosts=
MySuppliers.get(0).Price;//get_Main().ManufacturerPrice*HoldingR
ate;
HoldingCostsPerUnit=AvgPurchasePrice*HoldingRate;
if (CurrentDemand==0)
{
EconomicOrderQuantity=(sqrt( (2* BaseOPerationalDemand * 365
*OrderCosts)/(HoldingCosts) ));
}
```

```
else
{
EconomicOrderQuantity=(sqrt( (2* CurrentDemand * 365
*OrderCosts)/(HoldingCosts) ));
}
}
//==================================================
================================
//manufacturers
//==================================================
================================
//Manufacturers are different ==> lead time is fixed
ManufacturingLeadTime=2;
if ( Manufacturer>0)
{
ManufacturingLeadTime=2;
if (RollingDemandStats.count()>30)
{
SigmaDemand=RollingDemandStats.deviation();
CurrentDemand=RollingDemandStats.mean();
}
else
{
SigmaDemand=.1*CurrentDemand; //check that current demand is
set on startup
}
SafetyStock=(1.65*SigmaDemand*sqrt(ManufacturingLeadTime));
HoldingCosts=.2*get_Main().ManufacturerPrice*HoldingRate;
HoldingCostsPerUnit=HoldingCosts;
EconomicOrderQuantity=(int)(sqrt( (2*
CurrentDemand*365*OrderCosts)/(HoldingCosts ) ));
ROP=(ManufacturingLeadTime+2)*CurrentDemand+SafetyStock;
}
//==================================================
=======
//reset
//==================================================
========
MyStatistics.reset();
RollingDemandStats.reset(); // do we want to reset the stats every
tick - what is the frequency og this calc??????????????????????
traceln();
```

Function: CalculatingHoldingCosts

General

Return Type void

Code


```
Body StockHistory.add(Stock);
if (time()>=3 &&
time()>(TimeOfLastChangeCheck+PerformanceReviewPeriod -1 )
)
{
if (StockHistory.size()>PerformanceReviewPeriod)
{
int StartHere=(StockHistory.size()-1)-PerformanceReviewPeriod;
int FinishHere=StockHistory.size();
for (int i=StartHere;i<FinishHere;i++)
{
```

```
StockStats.add(StockHistory.get(i));
}
AverageStock=StockStats.mean();
}
}
```

Function: ConsumeStock

General

Return Type void

Code

```
Body if (Double.isNaN(Stock))
{
traceln();
}
if (Retailer>0)
{
if (Stock-CurrentDemand>0)
{
Stock=Stock-CurrentDemand;
}
if (Stock-CurrentDemand<0)
{
Stock=0;
}
}
AvailableStock=Stock-AllocatedStock;
if (Double.isNaN(Stock))
{
traceln();
}
```

Function: Ordering

Description: nothing obviously wrong

General

Access Type public

Return Type void

Code

```
Body //if ((Stock+ExpectedStock)<=ROP && Retailer>0 )
//{
/*traceln( "Stock = " + " " + Stock);
traceln( "ExpectedStock = " + " " + ExpectedStock);
traceln ("ROP = " + " " + ROP);
}*/
int count=0;
if (Died<1)
{
while ((Stock+ExpectedStock-AllocatedStock)<=(ROP ) &&
count<100)
{
```



```
if ((Retailer>0 || Wholesaler>0) && (MySuppliers.size()>0 ))
{
int i=MySuppliers.size();
double orderSize= (EconomicOrderQuantity/MySuppliers.size());
for (int j=0;j<MySuppliers.size();j++)
{
//create_Replenishment(2,EconomicOrderQuantity);
Order thisOrder=new Order (orderSize,this);
```

```
ExpectedStock=ExpectedStock+thisOrder.Quantity;
/*traceln("this Quantity = " + " " + thisOrder.Quantity);
traceln ("Buyer = " + " " + thisOrder.Buyer);*/
//Select supplier
send(thisOrder,MySuppliers.get(j));
NoOfOrdersPlaced=NoOfOrdersPlaced+1;
}
}
if (Manufacturer>0)
{
create_ManufacturingRequest(ManufacturingLeadTime,EconomicO
rderQuantity);
ExpectedStock=ExpectedStock+EconomicOrderQuantity;
NoOfManufactReq=NoOfManufactReq+1;
}
count=count+1;
}
}
if (count==99)
{
traceln();
}
//create an order ==> EOQ,buyer,
//create bank of expected deliveries to avoid double ordering
//Stock = stock+expected
//AvailableStock=Stock-expected-allocated
//think about no of suppliers - prioritise shortest leadtime
```

Function: CheckIfTooManyNSAs

General

Show At Runtime false

Return Type void

Code

Body
```
/*Actor sender=thisNSA.Sendor;
int count=0;
for (int i =0;i<NSAsReceived.size();i++)
{
if (NSAsReceived.get(i).Sendor==sender)
count+=1;
}
if (count > Tolerance)
{
//this no longer needs to be done on recept of NSA
get_Main().BadBoyRef=get_Main().BadBoyRef+1;
BadBoyClass thisBadBoyClass= new
BadBoyClass(thisNSA.Sendor,thisNSA.BadBoyRef);
```



```
BadBoys.add(thisBadBoyClass);
//AHPCalc(1);
SelectSuppliers();
}
create_CleanBadBoys(1,thisNSA.Sendor,thisNSA.BadBoyRef);*/
```

Arguments:

Name Type

thisNSA NSA

Function: CalculateDailyDemand

General

Return Type void

Code

```
Body if (Retailer>0)
{
OrderHistory1=CurrentDemand;
}
DailyDemand1.add(OrderHistory1);
OrderHistory1=0;
//DailyDemandHistory.add(OrderHistory1.sum());
//OrderHistory.reset();
if (DailyDemand1.size()>30)
{
for (int i=(DailyDemand1.size()-30);i<DailyDemand1.size();i++)
{
RollingDemandStats.add(DailyDemand1.get(i));
}
}
```

Function: CalculateFSValue

General

Return Type void

Code

```
Body //FS requirement =retailerGlobalRisk
```

Function: CalculateBuyerFlexibilityRequirement

General

Return Type void

Code

```
Body // Buyer commitment requirement = (1/mysuuplier size + actual
risk)/2
double actualRisk=0;
double riskModifier=0;
if (RiskAttitude<=.5)
{
riskModifier=.5-RiskAttitude;
actualRisk=get_Main().GlobalRetailBuyingRisk(
riskModifier*get_Main().GlobalRetailBuyingRisk);
```



```
if (actualRisk<0.2)
{
actualRisk=.2;
}
}
else
{
riskModifier=RiskAttitude-.5;
actualRisk=get_Main().GlobalRetailBuyingRisk(
riskModifier*get_Main().GlobalRetailBuyingRisk);
if (actualRisk>0.8)
{
actualRisk=.8;
}
}
if (MySuppliers.size()>0)
{
BuyerCommitmentRequirement=((1/MySuppliers.size())+actualRisk
)/2;
}
```

BuyingFSValue=actualRisk;

Function: RetailerSalesCash

General

Return Type void

Code

Body if (Retailer>0)

{

DailyRevenue.add(CurrentDemand*Price);

//Cash+=CurrentDemand*Price;

}

Function: MyGlobalRiskPerception

General

Return Type void

Code

Body //double temp=get_Main().GlobalRetailBuyingRisk;

if (get_Main().GlobalRetailBuyingRisk+((RiskAttitude.

5)*get_Main().GlobalRetailBuyingRisk)>1)

{

MyGlobalRiskPerceptionValue=1;

}

if (get_Main().GlobalRetailBuyingRisk+((RiskAttitude.

5)*get_Main().GlobalRetailBuyingRisk)<0);

{

MyGlobalRiskPerceptionValue=0;

}

if (get_Main().GlobalRetailBuyingRisk+((RiskAttitude.

5)*get_Main().GlobalRetailBuyingRisk)<1

&& get_Main().GlobalRetailBuyingRisk-((RiskAttitude.

5)*get_Main().GlobalRetailBuyingRisk)>0)

{

double temp=get_Main().GlobalRetailBuyingRisk;

MyGlobalRiskPerceptionValue=get_Main().GlobalRetailBuyingRisk;

//+((RiskAttitude-.5)*get_Main().GlobalRetailBuyingRisk);

}

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Calculating_commitment_16a6

Function: Adaptation

General

Return Type void

Code

Body //sell price

//calculate average demandif (DailyDemand1.size()>30)

TimeElapsed-=1;

if (TimeElapsed<0)

{

TimeElapsed=0;

}

//RollingDemandStats.reset();

===>

//double averageDemand=0;

double MaxPrice=0;

double MinPrice=0;

if (Retailer>0)

{

MaxPrice=get_Main().RetailMaxPrice;

MinPrice=get_Main().RetailMinPrice;

```
}
if (Wholesaler>0)
{
MaxPrice=get_Main().WholesaleMaxPrice;
MinPrice=get_Main().WholesaleMinPrice;
}
if (Manufacturer>0)
{
MaxPrice=get_Main().ManufacturerMaxPrice;
MinPrice=get_Main().ManufacturerMinPrice;
}
traceln();
if (Died<1)
{
if (DailyDemand1.size()>30)
{
for (int i=(DailyDemand1.size()-30);i<DailyDemand1.size();i++)
{
RollingDemandStats.add(DailyDemand1.get(i));
}
}
averageDemand=RollingDemandStats.mean();// what to do if no
stats//!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
if(TimeElapsed==0)
{
if (averageDemand>1.2*BaseOPerationalDemand)
{
TimeElapsed=10;
//too many orders increase price - constrained by upper limit
if ( 1.1*Price<=MaxPrice)
{
Price=1.1*Price;
}
if ( 1.1*Price>MaxPrice)
{
Price=MaxPrice;
}
}
if (averageDemand<.8*BaseOPerationalDemand)
{
// few orders lower price - constraned by lower limit
TimeElapsed=10;
if (Price*.9>=MinPrice)
{
Price=.9*Price;
}
if (Price*.9<MinPrice)
```



```
{
Price=MinPrice;
}
}
}
}
//check average demand aaginst base operational demand
//if Average demand >.9 of base operational demand then increase
sell price
//if <.8 of base operational demand then decrease sell price
//constrain the above around model run parametrised tier limits
//Cost Prioritisation (buy price)
```

```
//check whether average margin is as good as best
//if not then increase cost prioritisation
//if best do nothing
//!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!
//everybody will gravitate towards the lowest cost
```

Function: CalculateQualityValue

General

Return Type void

Code

```
Body // buying quality value is calculated as the average of GR and (1-
averagesupplier quality)
//calculate ASQ
double ASQ=0;
double actualRisk=0;
double riskModifier=0;
if (RiskAttitude<=.5)
{
riskModifier=.5-RiskAttitude;
actualRisk=get_Main().GlobalRetailBuyingRisk(
riskModifier*get_Main().GlobalRetailBuyingRisk);
if (actualRisk<0.2)
{
actualRisk=.2;
}
}
else
{
riskModifier=RiskAttitude-.5;
actualRisk=get_Main().GlobalRetailBuyingRisk(
riskModifier*get_Main().GlobalRetailBuyingRisk);
if (actualRisk>0.8)
{
actualRisk=.8;
}
}
if (MySuppliers.size()>0)
{
for (int i=0;i<MySuppliers.size(); i++)
{
ASQ+=MySuppliers.get(i).Quality;
}
BuyingQualityValue=( (1-ASQ/MySuppliers.size()) + actualRisk)/2;
}
```

Function: Changes

General

Return Type void

Code

```
Body //capture changes
//compare mySuppliersOld with Mysuppliers
// write my suppliers to old my suppliers (this needs to include
magnitude of relationship)
OldMysuppliersDetails.clear();
NewMysuppliersDetails.clear();
OldMysuppliersDetails1.clear();
NewMysuppliersDetails1.clear();
```

```
if (MySuppliers.size()>0)
{
for (int i =0;i<MySuppliers.size();i++)
{
MySupplierRelationships thisRelationship= new
MySupplierRelationships
(MySuppliers.get(i),this,CurrentDemand/MySuppliers.size(),0);
OldMysuppliersDetails.add(thisRelationship.Supplier.getIndex());
OldMysuppliersDetails1.add(thisRelationship.Supplier.getIndex());
}
}
// make changes ++ add my supplier details to
newmysupplierDetails
CreateSelectionIndexForSuppliers();
if (MySuppliers.size()>0)
{
for (int i =0;i<MySuppliers.size();i++)
{
MySupplierRelationships thisRelationship= new
MySupplierRelationships
(MySuppliers.get(i),this,CurrentDemand/MySuppliers.size(),0);
NewMysuppliersDetails.add(thisRelationship.Supplier.getIndex());
NewMysuppliersDetails1.add(thisRelationship.Supplier.getIndex());
}
}
// compare old with new
NewMysuppliersDetails.removeAll(OldMysuppliersDetails1);
OldMysuppliersDetails.removeAll(NewMysuppliersDetails1);
//List result = new ArrayList(NewMysuppliersDetails);
//result.removeAll(OldMysuppliersDetails);
/*if (NewMysuppliersDetails.size()>0 &&
OldMysuppliersDetails.size()>0)
{
for (int j=0;j<OldMysuppliersDetails.size();j++)
{
for (int i=0;i<NewMysuppliersDetails.size();i++)
{
if (NewMysuppliersDetails.size()>0 &&
OldMysuppliersDetails.size()>0)
{
if
(OldMysuppliersDetails.get(j).Supplier==NewMysuppliersDetails.get
(i).Supplier)
{
ToBeRemovedFromNew.add(NewMysuppliersDetails.get(i).Supplie
r.getIndex());
}
}
}
}
}
```



```
/*if (NewMysuppliersDetails.size()>0 && time()>0 )
{
for (int i=0;i<NewMysuppliersDetails.size();i++)
{
int buyerident=this.getIndex();
int supplierident=NewMysuppliersDetails.get(i);
double Magnitude=CurrentDemand/MySuppliers.size();
get_Main().file.println("time= " + " " + time () + " " +
```

```
"ManufacturerPriceVariation" + " " +
get_Main().ManufacturerPriceVariation + " " +
"ManufacturingMarginInput" + " " +
get_Main().ManufacturingMarginInput + " " +
"RetailPriceVariation" + " " + get_Main().RetailPriceVariation + " " +
"WholesalePriceVariation" + " " +
get_Main().WholesalePriceVariation +
"WholesalerMaginInput " + get_Main().WholesalerMaginInput + " "
+
"buyer " + " " + buyerident + " " +
"Supplier " + " " + supplierident + " " +
"Magnitude " + " " + Magnitude + " ");
}
}*/
if (NewMysuppliersDetails.size()>0 && time()>0 )
{
for (int i=0;i<NewMysuppliersDetails.size();i++)
{
int buyerident=this.getIndex();
int supplierident=NewMysuppliersDetails.get(i);
double Magnitude=CurrentDemand/MySuppliers.size();
get_Main().database.modify
("INSERT INTO Results VALUES ( " + time() + "," +
get_Main().ManufacturerPriceVariation +", "+
get_Main().ManufacturingMarginInput + ", "+
get_Main().RetailPriceVariation +" , "
+get_Main().WholesalePriceVariation +","
+get_Main().WholesalerMaginInput + " , "+ buyerident +" ,"
+supplierident + "," + Magnitude +") ");
}
}
/*if (OldMysuppliersDetails.size()>0 && time()>0 )
{
for (int i=0;i<OldMysuppliersDetails.size();i++)
{
int buyerident=this.getIndex();
int supplierident=OldMysuppliersDetails.get(i);
double Magnitude=CurrentDemand/MySuppliers.size();
get_Main().file.println("time= " + " " + time () + " " +
"buyer " + " " + buyerident + " " +
"Supplier " + " " + supplierident + " " +
" Magnitude " + " " + Magnitude + " ");
}
}
traceln();*/
// write any changes to file
```

Function: CollaboratingProcess

General

Return Type void

Code

```
Body MyCollaboratingSuppliers.clear();
//share information
/*if (MySuppliers.size()>0)
```



```
{
if (Collaboration>.3 && MySuppliers.get(0).Collaboration>.3)
{
MyCollaboratingSuppliers.add(MySuppliers.get(0)); //collaborate by
```

```
sharing demand data
}
}*/
// do something to do with tolerance and inertia
//other benefits to collaboration ==> levels of inter-organizational
collaboration
//
double BuyerDependency=0;
double SellerDependency=0;
double RelationalCommitment=0;
BuyerDependency=CurrentDemand/MySuppliers.size();
for ( int i=0;i<MySuppliers.size();i++)
{
SellerDependency=CurrentDemand/MySuppliers.get(i).CurrentDem
and;
RelationalCommitment=pow((BuyerDependency*SellerDependency
*get_Main().COVActualRetailerSuppliers),0.333);
if (RelationalCommitment>0.5)
{
MyCollaboratingSuppliers.add(MySuppliers.get(i));
}
```

Function: myFunction

General

Return Type void

Event: event

General

Trigger Type timeout

Mode cyclic

Recurrence 1

Occurence Time 0

Action if (CurrentDemand==0 && BaseOPerationalDemand==0 &&
EconomicOrderQuantity==0)

```
{
traceln();
}
```

Variable: Wholesaler

General

Type int

Initial Value 0

Variable: Stock

General

Type double

Initial Value 0

Variable: Price

General

Type double

Initial Value 0

Variable: Collaboration

General

Type double

Initial Value 0

Variable: CostPrioritisation

General

Type double

Initial Value 0

Variable: Manufacturer

General

Type int

Initial Value 0

Variable: Retailer

General

Type int

Initial Value 0

Variable: RiskAttitude

General

Type double

Initial Value 0

Variable: Died

General

Type double

Initial Value 0

Variable: SigmaDemand

General

Type double

Initial Value 0

Variable: OperatingCosts

General

Type double

Initial Value 0

Variable: OPeratingCostsPerUnit

General

Type double

Initial Value 0

Variable: BaseOPerationalDemand

General

Type double

Initial Value 0

Variable: CurrentDemand

General

Type double

Initial Value 0

Variable: JustBorn

General

Type double

Initial Value 0

Variable: TargetMarketShare

General

Type double

Initial Value 0

Variable: Cash

General

Type double

Initial Value 100 + uniform(20,40)

Variable: BuyingFSValue

General

Type double

Initial Value 0

Variable: BuyingLocationValue

General

Type double

Initial Value 0

Variable: BuyingPriceValue

General

Type double

Initial Value 0

Variable: BuyerCommitmentRequirement

General

Type double

Initial Value 0

Variable: Profit

General

Type double

Initial Value 0

Variable: CurrentIdealDemand

General

Type double

Initial Value 0

Variable: AvgPurchasePrice

General

Type double

Initial Value 0

Variable: AverageLeadTime

General

Type double

Initial Value 0

Variable: SafetyStock

General

Type double

Initial Value 0

Variable: EconomicOrderQuantity

General

Type double

Initial Value 0

Variable: OrderCosts

General

Type double

Initial Value 20

Variable: HoldingCostsPerUnit

General

Type double

Initial Value 0

Variable: HoldingRate

General

Type double

Initial Value .25

Variable: AverageStock

General

Type double

Initial Value 0

Variable: TimeOfLastChangeCheck

General

Type double

Initial Value 0

Variable: PerformanceReviewPeriod

General

Type int

Initial Value 30

Variable: AllocatedStock

General

Type double

Initial Value 0

Variable: AvailableStock

General

Type double

Initial Value 300

Variable: ROP

General

Type double

Initial Value 0

Variable: ExpectedStock

General

Type double

Initial Value 0

Variable: NoOfOrdersPlaced

General

Type int

Initial Value 0

Variable: ManufacturingLeadTime

General

Type double

Initial Value 0

Variable: NoOfManufactReq

General

Type double

Initial Value 0

Variable: MyConsumption

General

Type double

Initial Value 0

Variable: BuyPrice

General

Type double

Initial Value 0

Variable: OrderHistory1

General

Type double

Initial Value 0

Variable: PurchaseCostPerUnit

General

Type double

Initial Value 0

Variable: VariableCostPerUnit

General

Type double

Initial Value 0

Variable: NSASent

General

Type double

Initial Value 0

Variable: DistributionCostsPerUnit

General

Type double

Initial Value 0

Variable: CostPerKm

General

Type double

Initial Value .2

Variable: MyProduction

General

Type double

Initial Value 0

Variable: DistributionCostsPerUnit1

General

Type double

Initial Value 0

Variable: NoOfReplenishments

General

Type int

Initial Value 0

Variable: NSAreceived

General

Type double

Initial Value 0

Variable: OrdersReceived

General

Type double

Initial Value 0

Variable: Tolerance

General

Type double

Initial Value 10

Variable: MyGlobalRiskPerceptionValue

General

Type double

Initial Value 0

Variable: HoldingCosts

General

Type double

Initial Value 0

Variable: Quality

General

Type double

Initial Value 0

Variable: BuyingQualityValue

General

Type double

Initial Value 0

Variable: QualityValue

General

Type double

Initial Value 0

Variable: DailyProfitVar

General

Type double

Initial Value 0

Variable: DailyCostVar

General

Type double

Initial Value 0

Variable: DailyRevenueVar

General

Type double

Initial Value 0

Variable: actortestcount

General

Type double

Initial Value 0

Variable: averageDemand

General

Type double

Initial Value 0

Variable: TimeElapsed

General

Type double

Initial Value 0

Collection: SupplierUtilityCollection

General

Collection Class java.util.ArrayList

Element Class SupplierSelectionStuff

Collection: MySuppliers

General

Collection Class java.util.ArrayList

Element Class Actor

Collection: CommitmentToSuppliers

General

Collection Class java.util.ArrayList

Element Class RelationshipCommitment

Collection: CommitmentToCustomers

General

Collection Class java.util.ArrayList

Element Class RelationshipCommitment

Collection: MyCustomers

General

Collection Class java.util.ArrayList

Element Class Actor

Collection: MyRelationshipCommitments

General

Collection Class java.util.ArrayList

Element Class RelationshipCommitment

Collection: StockHistory

General

Collection Class java.util.ArrayList

Element Class Double

Collection: NSAsReceived

General

Collection Class java.util.ArrayList

Element Class NSA

Collection: BadBoys

General

Collection Class java.util.ArrayList

Element Class BadBoyClass

Collection: MyExistingCustomers

General

Collection Class java.util.ArrayList

Element Class Actor

Collection: MyCollaboratingSuppliers

General

Collection Class java.util.ArrayList

Element Class Actor

Collection: DailyDemand1

General

Collection Class java.util.ArrayList

Element Class Double

Collection: DailyProfit

General

Collection Class java.util.ArrayList

Element Class Double

Collection: tEST

General

Collection Class java.util.ArrayList

Element Class MarginStuff

Collection: OldMysuppliersDetails

General

Collection Class java.util.ArrayList

Element Class Integer

Collection: NewMysuppliersDetails

General

Collection Class java.util.ArrayList

Element Class Integer

Collection: ToBeRemovedFromNew

General

Collection Class java.util.ArrayList

Element Class Integer

Collection: ToBeRemovedFromOld

General

Collection Class java.util.ArrayList

Element Class Integer

Collection: OldMysuppliersDetails1

General

Collection Class java.util.ArrayList

Element Class Integer

Collection: NewMysuppliersDetails1

General

Collection Class java.util.ArrayList

Element Class Integer

Statechart Entry Point: Status

Transition: transition

General

Trigger Type condition

Condition Cash<10

Action /*if (Retailer>0)

```
{
get_Main().DeathRateRetailers +=1;
}
if (Wholesaler>0)
{
get_Main().DeathRateWholesalers +=1;
}
```



```
if (Manufacturer>0)
{
get_Main().DeathRateManufacturers +=1;
}
i*/
int type =0;
Died=1;
MySuppliers.clear();
double temp=0;
MySizeAndType.setFillColor(null);
//get_Main().ReallocateStock(this);
if (Retailer>0)
{
type=1;
}
if (Wholesaler>0)
{
type=2;
}
if (Manufacturer>0)
{
type=3;
}
if (type==3 || type==2)
{
traceln();
}
if (CurrentDemand>0)
{
temp=CurrentDemand;
}
else
{
temp=1;
}
//count no of type still alive
if (Manufacturer>0)
```

```
{
get_Main().CountManufacturersAlive();
}
//if >0 do nothing
//<1
// create new manufacturer
get_Main().RedistributeBaseOpDemand(temp,type,Stock);
```

State: Alive

State: Dead

General

Entry Action // make invisible

//record death - done

//modify birth rate

ActorGraphs: actorGraphs

General

Type ActorGraphs

Java Package Name calculating_commitment

Embedded Object Collection Type ARRAY_LIST_BASED

Statistics: MyStatistics

General

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: RollingDemandStats

General

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: StockStats

General

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: DailyVariableCosts

General

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: VariableCosts

General

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: DailyRevenue

General

Discrete true

Analysis Auto Update true

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Calculating_commitment_16a6

Recurrence 1

Statistics: DemandForOpCosts

General

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: OrderHistory

General

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: RevenueData

General

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: DailyCosts

General

Discrete true

Analysis Auto Update true

Recurrence 1

Statistics: RollingDailyProfit

General

Discrete true

Analysis Auto Update true

Recurrence 1

Text: text

General

Public false

Advanced

x 220

y 10

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Calculating_commitment_16a6

General

Alignment LEFT

Font Name SansSerif

Font Size 12

Bold Font Style true

Text Behavioral Values

Advanced

x 220

y 10

Persistent false

Text: text1

General

Public false

Advanced

x 30

y 10

General

Alignment LEFT

Font Name SansSerif

Font Size 12

Bold Font Style true

Text Agent State Variables

Advanced

x 30

y 10

Persistent false

Oval: MySizeAndType

Advanced

x 0

y 0

Radius X 10

Radius Y 10

Dynamic

On Click traceln (AvailableStock);

Line: Connection

Advanced

x 0

y 0

dX 10

dY 0

Line: Connection1

Advanced

x 0

y 0

dX 0

dY -10

Text: text3

General

Public false

Advanced

x 220

y 220

General

Alignment LEFT

Font Name SansSerif

Font Size 14

Bold Font Style true

Text Supplier Selection

Advanced

x 220

y 220

Text: text4

General

Public false

Advanced

x 490

y 220

General

Alignment LEFT

Font Name SansSerif

Font Size 14

Bold Font Style true

Text InventoryManagement

Advanced

x 490

y 220

Persistent false

Text: text2

Advanced

x 730

y 220

General

Alignment LEFT

Font Name SansSerif

Font Size 14

Bold Font Style true

Text Ordering

Advanced

x 730

y 220

Text: text5

Description: Flexibility ==> commtiment fit

NEED TO CALCULATE A BUYING COMMITMENT REQUIREMENT -

CREATE AN INDEX FOR ALL POTENTIAL SUPPLIERS BY COMPARING SUPPLIER COMMITMENT WITH BUYER REQUIRED COMMTIMENT

Delivery ==> some function of global risk

Finacial stability ==> index

Advanced

x 970

y 220

General

Alignment LEFT

Font Name SansSerif

Font Size 14

Bold Font Style true

Text Supplier Selection Criteria

Advanced

x 970

y 220

Active Object Class: ActorGraphs

Advanced

Auto-create Datasets true

Recurrence 1

Dataset Samples To Keep 100

Time Plot: plot2

General
Time Window 1000
Vertical Scale AUTO
Analysis Auto Update true
Recurrence 1
Dataset Samples To Keep 1000
Advanced
x 70
y 40
Width 240
Height 240
Appearance
Show Legend true
Legend Place SOUTH
Label Format MODEL_TIME_UNITS

Plot Items:

Title Type Dataset / Value Point Style Color Line Width Interpolation
DailyCostVar value get_Actor().DailyCostVar NONE gold true 2 LINEAR
DailyRevenueVar value get_Actor().DailyRevenueVar NONE yellowGreen true 2 LINEAR

Time Plot: Cash

General
Time Window 1000
Vertical Scale AUTO
Analysis Auto Update true
Recurrence 1
Dataset Samples To Keep 1000
Advanced
x 320
y 40
Width 800

Height 310
Appearance
Show Legend true
Legend Place SOUTH
Label Format MODEL_TIME_UNITS

Plot Items:

Title Type Dataset / Value Point Style Color Line Width Interpolation
BuyingFSValue value get_Actor().BuyingFSValue NONE darkMagenta true 2 LINEAR
BuyingLocationVal
ue
value get_Actor().BuyingLocationVal
ue
NONE orange true 2 LINEAR
BuyingPriceValue value get_Actor().BuyingPriceValue NONE darkKhaki true 2 LINEAR
BuyingQualityValue value get_Actor().BuyingQualityValu
e
NONE maroon true 2 LINEAR
BuyerCommitment
Requirement
value get_Actor().BuyerCommitment
Requirement

NONE mediumTurqu
oise
true 2 LINEAR

Java Class: ActorPrice

General

Java Class Type JAVA_CLASS

Text
```
/**
* ActorPrice
*/
public class ActorPrice implements java.io.Serializable {
public Actor Actor;
public double Price;
/**
* Default constructor
*/
public ActorPrice(){
}
/**
* Constructor initializing the fields
*/
public ActorPrice(Actor Actor, double Price){
this.Actor = Actor;
this.Price = Price;
}
@Override
public String toString() {
return
"Actor = " + Actor +" " +
"Price = " + Price +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```

Java Class: MarketShareScores

General

Java Class Type JAVA_CLASS

Text
```
/**
* MarketShareScores
*/
public class MarketShareScores implements java.io.Serializable {
public double TempMarketShareValue;
public Actor Ident;
/**
* Default constructor
*/
public MarketShareScores(){
}
/**
* Constructor initializing the fields
*/
public MarketShareScores(double TempMarketShareValue,
Actor Ident){
this.TempMarketShareValue = TempMarketShareValue;
```

```
this.Ident = Ident;
}
@Override
public String toString() {
return
"TempMarketShareValue = " + TempMarketShareValue +" " +
"Ident = " + Ident +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```

Java Class: SupplierFSScore

General

Java Class Type JAVA_CLASS

Text /**

```
* SupplierFSScore
*/
public class SupplierFSScore implements java.io.Serializable {
public Actor Supplier;
public double SupplierFS;
public double SupplierFSScore;
/**
* Default constructor
*/
public SupplierFSScore(){
}
/**
* Constructor initializing the fields
*/
public SupplierFSScore(Actor Supplier, double SupplierFS,
double SupplierFSScore){
```



```
this.Supplier = Supplier;
this.SupplierFS = SupplierFS;
this.SupplierFSScore = SupplierFSScore;
}
@Override
public String toString() {
return
"Supplier = " + Supplier +" " +
"SupplierFS = " + SupplierFS +" " +
"SupplierFSScore = " + SupplierFSScore +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```

Java Class: SupplierDistance

General

Java Class Type JAVA_CLASS

Text /**

```
* SupplierDistance
*/
public class SupplierDistance implements java.io.Serializable {
public Actor Supplier;
public double distance;
public double distanceRanking;
/**
* Default constructor
*/
public SupplierDistance(){
}
/**
* Constructor initializing the fields
*/
public SupplierDistance(Actor Supplier, double distance, double
distanceRanking){
this.Supplier = Supplier;
this.distance = distance;
this.distanceRanking = distanceRanking;
}
@Override
public String toString() {
return
"Supplier = " + Supplier +" " +
"distance = " + distance +" " +
"distanceRanking = " + distanceRanking +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```


Java Class: SupplierPriceIndex

General

Java Class Type JAVA_CLASS

Text /**

```
* SupplierPriceIndex
*/
public class SupplierPriceIndex implements java.io.Serializable {
public Actor Supplier;
public double Price;
public double PriceIndex;
/**
* Default constructor
*/
public SupplierPriceIndex(){
}
/**
* Constructor initializing the fields
*/
public SupplierPriceIndex(Actor Supplier, double Price, double
PriceIndex){
this.Supplier = Supplier;
this.Price = Price;
this.PriceIndex = PriceIndex;
}
@Override
```

```
public String toString() {
return
"Supplier = " + Supplier +" " +
"Price = " + Price +" " +
"PriceIndex = " + PriceIndex +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```

Java Class: SupplierSelectionStuff

General

Java Class Type JAVA_CLASS

Text
```
/**
* SupplierSelectionStuff
*/
public class SupplierSelectionStuff implements java.io.Serializable {
public Actor Supplier;
public double FSScore;
public double DistanceScore;
public double PriceScore;
public double FlexibilityScore;
```



```
public double QualityScore;
public double FSRank;
public double DistanceRank;
public double PriceRank;
public double FlexibilityRank;
public double QualityRank;
public double SupplierUtility;
/**
* Default constructor
*/
public SupplierSelectionStuff(){
}
/**
* Constructor initializing the fields
*/
public SupplierSelectionStuff(Actor Supplier, double FSScore,
double DistanceScore, double PriceScore, double FlexibilityScore,
double QualityScore,
double FSRank, double DistanceRank, double PriceRank,
double FlexibilityRank, double QualityRank, double SupplierUtility){
this.Supplier = Supplier;
this.FSScore = FSScore;
this.DistanceScore = DistanceScore;
this.PriceScore = PriceScore;
this.FlexibilityScore=FlexibilityScore;
this.QualityScore=QualityScore;
this.FSRank = FSRank;
this.DistanceRank = DistanceRank;
this.PriceRank = PriceRank;
this.FlexibilityRank=FlexibilityRank;
this.QualityRank=QualityRank;
this.SupplierUtility = SupplierUtility;
}
```

```
@Override
public String toString() {
return
"Supplier = " + Supplier +" " +
"FSScore = " + FSScore +" " +
"DistanceScore = " + DistanceScore +" " +
"PriceScore = " + PriceScore +" " +
"FlexibilityScore = " + FlexibilityScore + " " +
"QualityScore = " + QualityScore + " " +
"FSRank = " + FSRank +" " +
"DistanceRank = " + DistanceRank +" " +
"PriceRank = " + PriceRank +" " +
"FlexibilityRank = " + FlexibilityRank + " " +
"QualityRank = " + QualityRank + " " +
"SupplierUtility = " + SupplierUtility +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```

Java Class: ActorDemand

Java Class Type JAVA_CLASS

Text
```
/**
* ActorDemand
*/
public class ActorDemand implements java.io.Serializable {
public Actor Actor;
public double BuyingDemand;
public double SupplyDemand;
/**
* Default constructor
*/
public ActorDemand(){
}
/**
* Constructor initializing the fields
*/
public ActorDemand(Actor Actor, double BuyingDemand, double
SupplyDemand){
this.Actor = Actor;
this.BuyingDemand = BuyingDemand;
this.SupplyDemand = SupplyDemand;
}
@Override
public String toString() {
return
"Actor = " + Actor +" " +
"BuyingDemand = " + BuyingDemand +" " +
"SupplyDemand = " + SupplyDemand +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
```

```
private static final long serialVersionUID = 1L;
}
```

Java Class: RelationshipRisk

General

Java Class Type JAVA_CLASS

```
Text /**
* RelationshipRisk
*/
public class RelationshipRisk implements java.io.Serializable {
public Actor Supplier;
public double BuyerDependency;
public double SupplierDependency;
public double FlexibilityScore;
/**
* Default constructor
*/
public RelationshipRisk(){
}
```



```
/**
* Constructor initializing the fields
*/
public RelationshipRisk(Actor Supplier, double
BuyerDependency, double SupplierDependency, double
FlexibilityScore){
this.Supplier = Supplier;
this.BuyerDependency = BuyerDependency;
this.SupplierDependency = SupplierDependency;
this.FlexibilityScore = FlexibilityScore;
}
@Override
public String toString() {
return
"Supplier = " + Supplier +" " +
"BuyerDependency = " + BuyerDependency +" " +
"SupplierDependency = " + SupplierDependency +" " +
"FlexibilityScore = " + FlexibilityScore + " ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```

Java Class: RelationshipCommitment

General

Java Class Type JAVA_CLASS

```
Text /**
* RelationshipCommitment
*/
public class RelationshipCommitment implements
java.io.Serializable {
public Actor MyIdentity;
public Actor PartnerIdentity;
public String MyRole;
public String PartnerRole;
```

```
public double MyCommitment;
public double PartnerCommitment;
public double RelationshipRisk;
/**
* Default constructor
*/
public RelationshipCommitment(){
}
/**
* Constructor initializing the fields
*/
public RelationshipCommitment(Actor MyIdentity, Actor
PartnerIdentity, String MyRole, String PartnerRole, double
MyCommitment, double PartnerCommitment, double
RelationshipRisk ){
this.MyIdentity = MyIdentity;
this.PartnerIdentity = PartnerIdentity;
this.MyRole = MyRole;
```



```
this.PartnerRole = PartnerRole;
this.MyCommitment = MyCommitment;
this.PartnerCommitment=PartnerCommitment;
this.RelationshipRisk = RelationshipRisk;
}
@Override
public String toString() {
return
"MyIdentity = " + MyIdentity +" " +
"PartnerIdentity = " + PartnerIdentity +" " +
"MyRole = " + MyRole +" " +
"PartnerRole = " + PartnerRole +" " +
"MyCommitment = " + MyCommitment + " " +
"PartnerCommitment = " + PartnerCommitment + " " +
"RelationshipRisk = " + RelationshipRisk + " ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```

Java Class: Order

General

Java Class Type JAVA_CLASS

Text /**

```
* Order
*/
public class Order implements java.io.Serializable {
double Quantity;
Actor Buyer;
/**
* Default constructor
*/
public Order(){
}
/**
* Constructor initializing the fields
*/
```

```
public Order(double Quantity, Actor Buyer){
this.Quantity = Quantity;
this.Buyer = Buyer;
}
@Override
public String toString() {
return
"Quantity = " + Quantity +" " +
"Buyer = " + Buyer +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```


Java Class: NSA

General

Java Class Type JAVA_CLASS

Text /**

```
* NSA
*/
public class NSA implements java.io.Serializable {
public Actor Destination;
public double OrderQty;
public Actor Sendor;
public int BadBoyRef;
/**
* Default constructor
*/
public NSA(){
}
/**
* Constructor initializing the fields
*/
public NSA(Actor Destination, double OrderQty, Actor Sendor, int
BadBoyRef){
this.Destination = Destination;
this.OrderQty = OrderQty;
this.Sendor = Sendor;
this.BadBoyRef=BadBoyRef;
}
@Override
public String toString() {
return
"Destination = " + Destination +" " +
"OrderQty = " + OrderQty +" " +
"Sendor = " + Sendor +" " +
"BadBoyRef = " + BadBoyRef +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```

Java Class: BadBoyClass

General

Java Class Type JAVA_CLASS

Text /**

* BadBoyClass

*/

public class BadBoyClass implements java.io.Serializable {

public Actor BadBoy;

public int BadBoyRef;

/**

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* Default constructor

*/

public BadBoyClass(){

}

/**

* Constructor initializing the fields

*/

public BadBoyClass(Actor BadBoy, int BadBoyRef){

this.BadBoy = BadBoy;

this.BadBoyRef = BadBoyRef;

}

@Override

public String toString() {

return

"BadBoy = " + BadBoy +" " +

"BadBoyRef = " + BadBoyRef +" ";

}

/**

* This number is here for model snapshot storing purpose

* It needs to be changed when this class gets changed

*/

private static final long serialVersionUID = 1L;

}

Java Class: MyValues

General

Java Class Type JAVA_CLASS

Text /**

* MyValues

*/

public class MyValues implements java.io.Serializable {

public Actor ThisActor;

public double SDDemand;

public double SDDemandValue;

public double FS;

public double FSValue;

public double Flexibility;

public double FlexibilityValue;

/**

* Default constructor

*/

public MyValues(){

}

/**

* Constructor initializing the fields

*/

public MyValues(Actor ThisActor, double SDDemand, double

SDDemandValue, double FS, double FSValue, double Flexibility,

```
double FlexibilityValue){
this.ThisActor = ThisActor;
this.SDDemand = SDDemand;
this.SDDemandValue = SDDemandValue;
this.FS = FS;
this.FSValue = FSValue;
this.Flexibility = Flexibility;
```



```
this.FlexibilityValue = FlexibilityValue;
}
@Override
public String toString() {
return
"ThisActor = " + ThisActor +" " +
"SDDemand = " + SDDemand +" " +
"SDDemandValue = " + SDDemandValue +" " +
"FS = " + FS +" " +
"FSValue = " + FSValue +" " +
"Flexibility = " + Flexibility +" " +
"FlexibilityValue = " + FlexibilityValue +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```

Java Class: MySupplierDetails

General

Java Class Type JAVA_CLASS

Text
```
/**
* MySupplierDetails
*/
public class MySupplierDetails implements java.io.Serializable {
public Actor Supplier;
public Actor StartDate;
/**
* Default constructor
*/
public MySupplierDetails(){
}
/**
* Constructor initializing the fields
*/
public MySupplierDetails(Actor Supplier, Actor StartDate){
this.Supplier = Supplier;
this.StartDate = StartDate;
}
@Override
public String toString() {
return
"Supplier = " + Supplier +" " +
"StartDate = " + StartDate +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
```

```
private static final long serialVersionUID = 1L;
}
```

Java Class: DeliveryStuff

General

Java Class Type JAVA_CLASS

```
Text /**
* DeliveryStuff
*/
public class DeliveryStuff implements java.io.Serializable {
public Actor thisActor;
public double SigmaDemand;
/**
* Default constructor
*/
public DeliveryStuff(){
}
/**
* Constructor initializing the fields
*/
public DeliveryStuff(Actor thisActor, double SigmaDemand){
this.thisActor = thisActor;
this.SigmaDemand = SigmaDemand;
}
@Override
public String toString() {
return
"thisActor = " + thisActor +" " +
"SigmaDemand = " + SigmaDemand +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```

Java Class: MarginStuff

General

Java Class Type JAVA_CLASS

```
Text /**
* MarginStuff
*/
public class MarginStuff implements java.io.Serializable {
public Actor thisActor;
public double Margin;
/**
* Default constructor
*/
public MarginStuff(){
}
/**
* Constructor initializing the fields
*/
public MarginStuff(Actor thisActor, double Margin){
this.thisActor = thisActor;
this.Margin = Margin;
}
```

```
@Override
public String toString() {
return
"thisActor = " + thisActor +" " +
"Margin = " + Margin +" ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```

Java Class: MySupplierRelationships

General

Java Class Type JAVA_CLASS

```
Text /**
* MySupplierRelationships
*/
public class MySupplierRelationships implements
java.io.Serializable {
Actor Supplier;
Actor Buyer;
double Magnitude;
int ToBeRemoved;
/**
* Default constructor
*/
public MySupplierRelationships(){
}
/**
* Constructor initializing the fields
*/
public MySupplierRelationships(Actor Supplier, Actor Buyer ,
double Magnitude, int ToBeRemoved){
this.Supplier = Supplier;
this.Buyer = Buyer;
this.Magnitude = Magnitude;
this.ToBeRemoved=ToBeRemoved;
}
@Override
public String toString() {
return
"Supplier = " + Supplier +" " +
"Buyer = " + Buyer +" " +
"Magnitude = " + Magnitude +" " +
"ToBeRemoved = " + ToBeRemoved + " ";
}
/**
* This number is here for model snapshot storing purpose<br>
* It needs to be changed when this class gets changed
*/
private static final long serialVersionUID = 1L;
}
```


Simulation Experiment: Simulation

General

Active Object Class Main

Random Number Generation Type fixedSeed

Seed Value 3245

Advanced

Maximum Available Memory 64

Differention Equations Method EULER

Mixed Equations Method RK45_NEWTON

Algebraic Equations Method MODIFIED_NEWTON

Absolute Accuracy 1.0E-5

Time Accuracy 1.0E-5

Relative Accuracy 1.0E-5

Fixed Time Step 0.0010

Presentation Top Group Persistent true

Model Time

Stop Option Stop at specified time

Initial Time 0.0

Final Time 1000.0

Presentation

CPU Time Balance ratio_1_2

Execution Mode realTimeScaled

Real Time Scale 1.0

Window

Title Calculating_commitment : Simulation

Real Time Of Simulation false

Text: text

Advanced

x 40

y 30

General

Alignment LEFT

Font Name Serif

Font Size 28

Bold Font Style true

Text Calculating_commitment

Advanced

Page 119 of 129

Calculating_commitment_16a6

x 40

y 30

Text: text1

Advanced

x 40

y 63

General

Alignment LEFT

Font Name Serif

Font Size 16

Italic Font Style true

Text Experiment setup page

Advanced

x 40

y 63

Button: button

General

Label Text Run the model and switch to Main view

Action if (getState() == IDLE)

run();

getPresentation().setPresentable(getEngine().getRoot());

Advanced

Font Name Dialog

Font Size 11

x 40

y 120

Width 330

Height 30

Dynamic

Dynamic: Label getState() == IDLE ?

"Run the model and switch to Main view" :

"Switch to Main view"

Parameter Variation Experiment: ParametersVariation

General

Active Object Class Main

Random Number Generation Type randomSeed

Use Freeform Parameters false

Number Of Runs 10

Advanced

Maximum Available Memory 64

Before Simulation Run variable=getCurrentReplication();

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Calculating_commitment_16a6

root.Replication=getCurrentReplication();

if (root.Replication>0)

{

traceln();

}

root.ExperimentVersion=getCurrentIteration();

After Simulation Run //variable=getCurrentReplication();

//root.Replication=getCurrentReplication();

After Iteration Code //variable=getCurrentReplication();

Differention Equations Method EULER

Mixed Equations Method RK45_NEWTON

Algebraic Equations Method MODIFIED_NEWTON

Absolute Accuracy 1.0E-5

Time Accuracy 1.0E-5

Relative Accuracy 1.0E-5

Fixed Time Step 0.0010

Model Time

Stop Option Stop at specified time

Initial Time 0.0

Final Time 1000.0

Presentation

CPU Time Balance ratio_1_2

Window

Title Calculating_commitment_16a2 : ParametersVariation

Model Time false

Experiment Progress true

Parameter Variation Experiment Parameters:

Value

Parameter Type Min Max Step

MarketDifferentiatio

n

FIXED

RetailPriceVariatio

n

RANGE .05 .2 .15

WholesalePriceVari

ation

RANGE .05 .2 .15

ManufacturerPrice

Variation

RANGE .05 .2 .15

ManufacturingMarg

inInput

RANGE .35 .5 .15

WholesalerMaginIn

put

RANGE .15 .3 .15

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Calculating_commitment_16a6

Variable: variable

General

Type double

Initial Value getCurrentReplication()

Time Plot: plot

General

Time Window 1000

Vertical Scale AUTO

Analysis Auto Update true

Recurrence 1

Dataset Samples To Keep 1000

Advanced

x 350

y 190

Width 410

Height 250

Appearance

Show Legend true

Legend Place SOUTH

Label Format MODEL_TIME_UNITS

Plot Items:

Title Type Dataset / Value Point Style Color Line Width Interpolation

Replication value getCurrentReplication() NONE darkMagenta true 2 LINEAR

Itteration value getCurrentIteration() NONE orange true 2 LINEAR

Dataset Title 2 value variable NONE darkKhaki true 2 LINEAR

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Calculating_commitment_16a6

Text: text

Advanced

x 10

y 10

General

Alignment LEFT

Font Name Serif

Font Size 28

Bold Font Style true

Text Calculating_commitment_16a2 : ParametersVariation

Advanced

x 10

y 10

Text: text1

Advanced

x 10

y 50

General

Alignment LEFT

Font Name Serif

Font Size 16

Italic Font Style true

Text Parameter Variation Experiment

Advanced

x 10

y 50

Text: text2

Advanced

x 20

y 130

General

Alignment LEFT

Font Name SansSerif

Font Size 12

Text Iteration:

Advanced

x 20

y 130

Text: text3

General

Color darkSlateBlue

Advanced

x 240

y 130

General

Alignment RIGHT

Font Name SansSerif

Font Size 12

Text ?

Advanced

x 240

y 130

Dynamic

Dynamic: Visible getCurrentIteration() > 0

Dynamic: Text format(getCurrentIteration())

Line: line

Advanced

x 10

y 150

dX 240

dY 0

Text: text4

Advanced

x 20

y 160

General

Alignment LEFT

Font Name SansSerif

Font Size 12

Bold Font Style true

Text Parameters

Advanced

x 20

y 160

Text: text5

Advanced

x 20

y 190

General

Alignment LEFT

Font Name SansSerif

Font Size 12

Text MarketDifferentiation

Advanced

x 20

y 190

Text: text6

General

Color darkSlateBlue

Advanced

x 240

y 190

General

Alignment RIGHT

Font Name SansSerif

Font Size 12

Text ?

Advanced

x 240

y 190

Dynamic

Dynamic: Visible getCurrentIteration() > 0

Dynamic: Text format(MarketDifferentiation)

Text: text7

Advanced

x 20

y 210

General

Alignment LEFT

Font Name SansSerif

Font Size 12

Text RetailPriceVariation

Advanced

x 20

y 210

Text: text8

General

Color darkSlateBlue

Advanced

x 240

y 210

General

Alignment RIGHT

Font Name SansSerif

Font Size 12

Text ?

Advanced

x 240

y 210

Dynamic

Dynamic: Visible getCurrentIteration() > 0

Dynamic: Text format(RetailPriceVariation)

Text: text9

Advanced

x 20

y 230

General

Alignment LEFT

Font Name SansSerif

Font Size 12

Text WholesalePriceVariation

Advanced

x 20

y 230

Text: text10

General

Color darkSlateBlue

Advanced

x 240

y 230

General

Alignment RIGHT

Font Name SansSerif

Font Size 12

Text ?

Advanced

x 240

y 230

Dynamic

Dynamic: Visible getCurrentIteration() > 0

Dynamic: Text format(WholesalePriceVariation)

Text: text11

Advanced

x 20

y 250

General

Alignment LEFT

Font Name SansSerif

Font Size 12

Text ManufacturerPriceVariation

Advanced

x 20

y 250

Text: text12

General

Color darkSlateBlue

Advanced

x 240

y 250

General

Alignment RIGHT

Font Name SansSerif

Font Size 12

Text ?

Advanced

x 240

y 250

Dynamic

Dynamic: Visible getCurrentIteration() > 0

Dynamic: Text format(ManufacturerPriceVariation)

Text: text13

Advanced

x 20

y 270

General

Alignment LEFT

Font Name SansSerif

Font Size 12

Text ManufacturingMarginInput

Advanced

x 20

y 270

Text: text14

General

Color darkSlateBlue

Advanced

x 240

y 270

General

Alignment RIGHT

Font Name SansSerif

Font Size 12

Text ?

Advanced

x 240

y 270

Dynamic

Dynamic: Visible getCurrentIteration() > 0

Dynamic: Text format(ManufacturingMarginInput)

Text: text15

Advanced

x 20

y 290

General

Alignment LEFT

Font Name SansSerif

Font Size 12

Text WholesalerMaginInput

Advanced

x 20

y 290

Text: text16

General

Color darkSlateBlue

Advanced

x 240

y 290

General

Alignment RIGHT

Font Name SansSerif

Font Size 12

Text ?

Advanced

x 240

y 290

Dynamic

Dynamic: Visible getCurrentIteration() > 0

Dynamic: Text format(WholesalerMaginInput)

Button: button

General

Label Text Run Experiment

Dynamic: Enable getState() == IDLE

Action run();

Advanced

Font Name Dialog

Font Size 11

x 10

y 80

Width 180

Height 30

Appendix B Curve estimations

Model Summary and Parameter Estimates

Dependent CoM

Scenario 1			Model Summary					Parameter Estimates	
			R Square	F	df1	df2	Sig.	Constant	b1
1	1	Exponential	.990	13758.756	1	134	.000	1857.599	.000
	2	Exponential	.961	4251.116	1	174	.000	1894.140	-.001
	3	Exponential	.979	2938.888	1	64	.000	1995.762	.000
	4	Exponential	.502	609.867	1	606	.000	2313.594	.000
	5	Exponential	.890	6820.357	1	845	0.000	1770.868	.000
2	1	Exponential	.980	2125.609	1	43	.000	189.691	.000
	2	Exponential	.970	418.517	1	13	.000	174.083	.000
	3	Exponential	.962	356.169	1	14	.000	228.452	.000
	4	Exponential	.799	123.322	1	31	.000	144.013	.000
	5	Exponential	.490	58.616	1	61	.000	181.430	.000
3	1	Exponential	.985	1399.710	1	22	.000	2189.300	-.001
	2	Exponential	.888	5663.228	1	713	0.000	2265.521	-.001
	3	Exponential	.924	1414.076	1	117	.000	1967.101	.000
	4	Exponential	.966	1241.052	1	44	.000	1908.574	-.001
	5	Exponential	.750	2359.293	1	787	.000	1681.985	.000
4	1	Exponential	.942	547.324	1	34	.000	119.101	.000
	2	Exponential	.880	314.215	1	43	.000	111.196	.000
	3	Exponential	.958	525.394	1	23	.000	171.399	-.001
	4	Exponential	.871	107.743	1	16	.000	112.755	.000
	5	Exponential	.776	72.694	1	21	.000	82.642	.000
5	1	Exponential	.981	307.795	1	6	.000	447.282	-4.278E-05
	2	Exponential	.497	414.439	1	419	.000	268.079	.000
	3	Exponential	.687	13.192	1	6	.011	412.563	-.001
	4	Exponential	1.000		1	0		458.830	-7.459E-05
	5	Exponential	.806	28.997	1	7	.001	435.933	.000
6	1	Exponential	.252	218.544	1	649	.000	1024.918	-.001
	2	Exponential	.749	992.762	1	332	.000	1595.768	.000
	3	Exponential	.402	155.748	1	232	.000	743.965	.000
	4	Exponential	.865	531.065	1	83	.000	1252.775	.000
	5	Exponential	.488	10.471	1	11	.008	313.709	.000
7	1	Exponential	.829	141.052	1	29	.000	96.092	-.001
	2	Exponential	.949	148.816	1	8	.000	88.545	-.001
	4	Exponential	.897	8.728	1	1	.208	1290.575	-.001
	5	Exponential	.731	87.071	1	32	.000	61.766	.000
8	1	Exponential	.822	268.225	1	58	.000	897.444	-.001
	3	Exponential	.689	1394.545	1	630	.000	915.387	-.001
	4	Exponential	.854	105.457	1	18	.000	453.480	-.001
	5	Exponential	.885	23.182	1	3	.017	3702.326	-.002
9	1	Exponential	.862	1094.868	1	176	.000	602.191	.000
	3	Exponential	.953	8299.597	1	408	.000	417.377	.000
	4	Exponential	.940	423.827	1	27	.000	567.453	.000
	5	Exponential	.963	259.733	1	10	.000	564.945	.000
10	1	Exponential	.872	837.565	1	123	.000	203.405	.000
	2	Exponential	.931	841.209	1	62	.000	297.766	.000
	3	Exponential	1.000		1	0		317.859	.000
	4	Exponential	.929	1443.917	1	111	.000	299.992	.000
	5	Exponential	.999	2252.948	1	3	.000	188.055	.000

Appendix C Example of full results

Experiment	Replication	Time	SumOfMagnitude	Count_GT_Mag
1	1	1	8429.484738	341
1	1	2	11794.00873	246
1	1	3	3908.972767	605
1	1	4	3499.576807	677
1	1	6	3605.458374	659
1	1	8	3723.743601	636
1	1	16	3651.430862	650
1	1	18	3699.014547	641
1	1	21	3620.532344	657
1	1	26	601.3713014	1575
1	1	32	276.0000000	1631
1	1	33	10549.08849	278
1	1	38	1954.548704	918
1	1	40	1894.339292	935
1	1	41	1894.339292	935
1	1	42	1930.595529	923
1	1	47	1995.942201	906
1	1	48	1821.084147	961
1	1	50	2473.706084	802
1	1	56	4812.374662	488
1	1	57	10092.90931	297
1	1	63	10122.38084	295
1	1	76	2732.851542	779
1	1	78	3049.010149	743
1	1	79	2933.576779	759

of German and US supply management professionals", *International Journal of Technology Policy and Management,* vol. 8, no. 4, pp. 401.